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Global warming and its impacts on Asia - From the IPCC AR4

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ABSTRACT

The summer 2010 was characterized by extreme weathers all over the world. Since its establishment in 1988, the Intergovernmental Panel on Climate Change (IPCC) has produced a series of Assessment Reports, ARs, (1990, 1995, 2001 and 2007), which have become standard works and have played a major role in assisting governments to adopt and implement policies in response to climate change. This article is based on the materials contained in the AR4: WG1 report on "The Physical Sciences Basis", WG2 report on "Impacts, Adaptation and Vulnerability", WG3 report on "Mitigation of Climate Change", and the Synthesis Report with its Summary for Policymakers. The assessment confirms that climate change is occurring now, mostly as a result of human activities; it illustrates the impacts of global warming already under way and to be expected in future, and describes the potential for adaptation of society to reduce its vulnerability. The assessment and projections of climate change and associated socio-economic consequences are vital for the future of Asian region, particularly in the developing countries and countries with economies in transition.

***Keywords**: IPCC, AR4, global warming, Asia*

1. WARMING IS UNEQUIVOCAL

Warming of the climate system is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow band ice and rising global average sea level, says the AR4 (Assessment Report 4, 2007). Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature since 1850. Figure 1 was taken from WG I report of AR4. Average Northern Hemisphere temperature during the second half of the 20th century were very likely (> 90% probability) higher than during any other 50-year period in the last 500 years and likely (> 66% probability) the highest in at least the past 1,300 years.
According to the news release by the Japan Meteorological Agency (JMA) on June 15, 2010, the seasonal anomaly of the global mean surface temperature for March to May (boreal spring season) in 2010 hit the highest record with +0.41°C on a par with the same months in 1998 since 1981, the earliest year for which the JMA estimated global temperature anomalies (Figure 2). Seen from a longer perspective, the global mean temperature for March to May have been on a rising trend at a rate of +0.73°C per century. According to the JMA, the warming is

mainly caused by the global buildup of anthropogenic GHGs in the atmosphere, but the El Nino episode that started summer 2009, as well as natural climate fluctuations of various durations, partly attributed to the warmer globe.
The AR4 states that some extreme weather events have changed in frequency and/or intensity over the last 50 years. It is very likely (> 90% probability of occurrence) that, during the past 50 years, cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is likely (> 66% probability) that heat waves have become more frequent over most land areas, that the frequency of heavy precipitation events has increased over most areas, and that the incidence of extreme high sea level has increased worldwide since 1975.

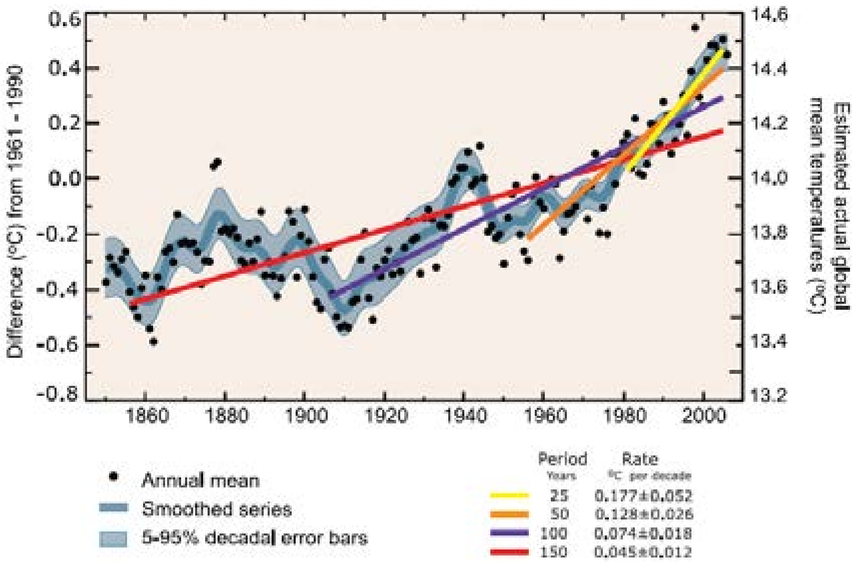

Figure 1: Global Mean Temperature

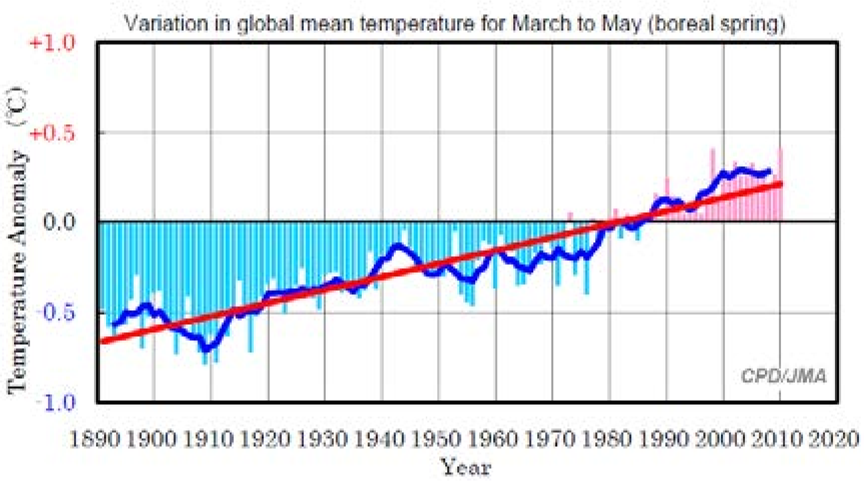

Figure 2: Long-term surface temperature anomalies for March to May over the globe (JMA) - Anomalies are deviations from the normal (1971-2000 average). The bars indicate annual anomalies, the blue line 5-year running mean, and the red line a long-term linear trend.

2. MOST GHG INCREASE IS DUE TO ANTHROPOGENIC ORIGIN

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Carbon dioxide (CO_2) emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 giga-tonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004. The rate of growth of CO_2-eq emissions was much higher during the recent 10-year period of 1995-2004 (0.92 $GtCO_2$-eq per year) than during the previous period of 1970-1994 (0.43 $GtCO_2$-eq per year). Figures 3 and 4 were taken from the WG1 report, with the latter in a slightly modified form that appears in the Synthesis Report.

Advances since the 2001 Third Assessment Report (TAR) show that discernible human influences extend beyond average temperature to other aspects of climate. Recent studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the TAR (2001) which could only conclude that "there is high confidence that recent regional changes in temperature have had discernable impacts on physical and biological systems."

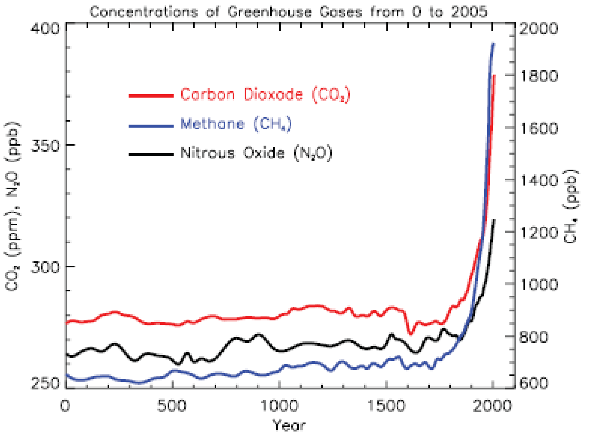

Figure 3: Atmospheric concentrations of long-lived GHGs over the last 2,000 years.

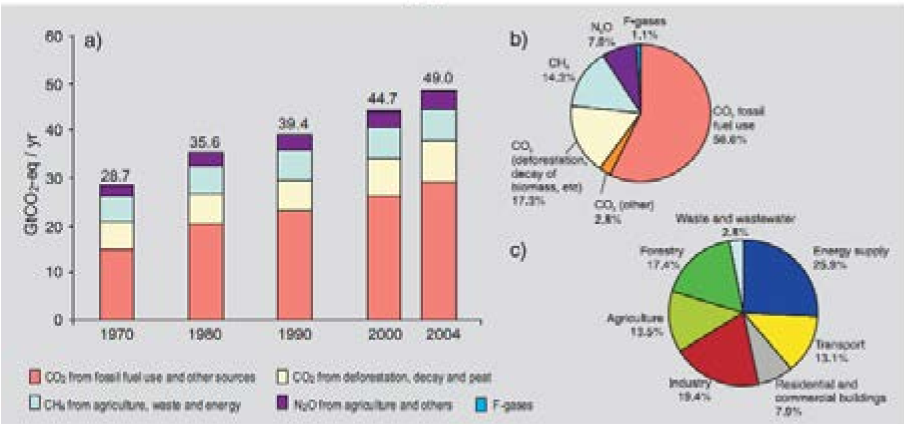

Figure 4: Global Anthropogenic GHG Emissions (Synthesis Report of AR4)
(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004,
(b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq, and (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq (Forestry includes deforestation.)

3. WARMING IS DUE TO ANTHROPOGENIC GHG CONCENTRATIONS

The AR4 concludes that most of the observed increase in global average temperatures since the mid-20th century is very likely (> 90% probability) due to the observed increase in anthropogenic GHG concentrations. This is an advance since the TAR's conclusion: Most of the observed warming over the last 50 years is likely to have been due to the increase in GHG concentrations.

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases due to anthropogenic causes.

Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming. There is high confidence (About 8 out of 10 chances) that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:

- enlargement and increased numbers of glacial lakes
- increasing ground instability in permafrost regions and rock avalanches in mountain regions
- changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and predators at high levels of the food web.

Based on growing evidence, there is high confidence (About 8 out of 10 chances) that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality.

According to the AR4, human influences have:

- very likely (> 90% probability) contributed to sea level rise during the latter half of the 20th century,
- likely (> 66% probability) contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns,
- likely (> 66% probability) increased temperatures of extreme hot nights, cold nights, and cold days,
- more likely than not (33 to 66% probability) increased risk of heat waves, area affected by droughts since the 1970s and frequency of heavy precipitation events.

Following cautious examinations of past persisting anomalies of weather, the WG1 report of the AR4 lists the following 6 climate events as extreme weathers:

- Drought in Central and Southwest Asia, 1998-2003
- Drought in Australia, 2002-2003
- Drought in Western North America, 1999-2004
- Floods in Europe, Summer 2002
- Heat Wave in Europe, Summer 2003
- The 2005 Tropical Storm Season in the North Atlantic

To the question "Are extreme events, like heat waves, droughts or floods, expected to change the Earth's climate changes?" the AR4 answers "Yes." Although the type, frequency and intensity of extreme events are expected to vary as Earth's climate changes, these changes could occur even for relatively small mean climate changes (Chapter 10, WG1 report). But, when asked how likely major or abrupt climate changes are, the report answers that, although the occurrence of such changes becomes increasingly more likely, such abrupt climate changes are not considered to occur in the 21st century (Chapter 10, WG1 report).

4. GENERAL IMPACTS OF GLOBAL WARMING

By the mid- to late-21st century, it is projected virtually certain (> 99% probability) that, over most land areas, there will be warmer and more frequent hot days and nights due to changes in extreme weather and climate events. These do not take into account any changes or developments in adaptive capacity.
Examples of major projected impacts in different sectors associated with the above climate change are:

- In agriculture, forestry and ecosystems: Increased yields in colder environments, decreased yields in warmer environments, decreased yields in low-altitudes due to reduced water availability, and increased insect outbreaks
- In water resources: Effects on water resources in some dry regions at mid-latitudes and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- In human health sector: Reduced human mortality from decreased cold exposure, ill-effects to human health in populations with low adaptive capacity
- In industry, settlement and society: Reduced energy demand to heating, increased demand for cooling, declining air quality in cities, reduced disruption to transport due to snow/ice, effects on winter tourism,

and in general,

- In low-lying coastal systems: Various kinds of effects due to sea level rise and increased risk from extreme weather events.

5. IMPACTS ON ASIA

5.1 Recent and Future Trends

Asia is the most populous continent with its total population in 2002 reported to be about 3.9 billion, of which almost 61% lives in rural areas and 38.5% within 100 km of the coast. The population growth projections for Asia range between 1.54 billion people in 2050 and 4.5 billion people in 2100.
Increasing surface air temperature trends have been observed all across of Asia. The observed increases during recent decades ranged between less than 1°C to 3°C per century. Recent trends show the increasing tendency in the intensity and frequency of extreme weather events in Asia. Severe heat waves with significantly longer duration have been observed in many countries. Generally, the frequency of occurrence of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides, and debris and mud flows, while the number of rainy days and total annual amount of precipitation has decreased.

Increasing frequency and intensity of droughts in many parts of Asia are attributed largely to a rise in temperature particularly during the summer and normally drier months. In parts of China, the rise in temperature and decreases in precipitation, along with increasing water use, have caused water shortages that led to drying up of lakes and rivers. In India, Pakistan, Nepal and Bangladesh, water shortages have been attributed to rapid urbanization and industrialization, population growth and inefficient water use, which are aggravated by changing climate. Decreasing precipitation and increasing temperature commonly associated with ENSO have been reported to increase water shortage, particularly in parts of Asia where water resources are already under stress from growing water demands and inefficient water use. Production of rice, maize and wheat has declined in the past few decades in many parts of Asia due to increasing water stress arising partly from increasing temperature, increasing frequency of El Nino and reduction in the number of rainy days.
The coastlines in monsoon Asia are cyclone-prone, and about 42% of the world's total tropical cyclones occur in this region. The combined extreme climatic and non-climatic events caused coastal flooding, resulting in substantial economic losses and fatalities. Wetlands in the major river deltas have been significantly altered in recent years due to large scale sedimentation, and use conversion, logging and human settlement. Salt water from the Bay of Bengal is reported to have penetrated 100 km or more inland during the dry season. Severe droughts and unregulated groundwater withdrawal have also resulted in sea-water intrusion in the coastal plains of China.
A large number of deaths due to heat waves mainly among the poor, elderly and laborers have been reported in India during the past five years. Serious health risks associated with extreme summer temperatures and heat waves have been reported in Siberian cities. In South Asia, endemic morbidity and mortality due to diarrhoeal disease and outbreaks of other infectious diseases is linked to poverty and poor hygiene, such as lack of access to safe drinking water and poor sewerage system, compounded by the effect of high temperatures on bacterial proliferation.
Increasing intensity and spread of forest fires in Asia were observed in the past 20 years, largely attributed to the rise in temperature and decline in precipitation in combination with increasing intensity of land uses. Fires in Siberian peat lands have increased dramatically. The 1997/98 ENSO event in Indonesia triggered forest and bush fires, with serious domestic and trans-boundary pollution consequences.

5.2 Future Impacts

Food security: Half the world's population is located in Asia. There are serious concerns about the prevalence of malnutrition among poorer and marginal groups, particularly rural children, and about the large number of people below the poverty line in many countries.
The net cereal production in South Asian countries is projected to decline at least between 4 to 10% by the end of this century under the most conservative climate change scenario. Climate change can affect not only crop production per unit area but also the area of production. Most of the arable land that is suitable for cultivation in Asia is already in use.

Consumption of animal products such as meat and poultry has increased steadily in Asia. However, cool temperate grassland is projected to shift northward with climate change and the net primary productivity will decline. The Asia-Pacific region is the world's largest producer of fish. Future changes in ocean currents, sea level, sea-water temperature, salinity, wind speed and direction, strength of upwelling, the mixing layer thickness and predator response to climate change have the potential to substantially alter fish breeding habitats and food supply for fish and ultimately the abundance of fish populations in Asian waters.

Increasing urbanization and population in Asia will likely result in increased food demand and reduced supply due to limited availability of cropland area and yield declines projected in most simulations. Food supply or ability to purchase food directly depends on income and price of the products. The global cereal prices have been projected to increase more than three-fold by the 2080s. The risk of hunger is likely to remain very high in several developing countries.

Water availability and quality: Changes in seasonality and amount of water flows from river systems are likely to occur due to climate change. Changes in runoff of river basins could have a significant effect on the power output of hydropower generating countries. Likewise, surface water availability from major rivers may also be affected by alteration of river flows. In North China, irrigation from surface and groundwater sources will meet only 70% of the water requirement for agricultural production, due to the effects of climate change and increasing demand. The maximum monthly flow of the Mekong is estimated to increase by 35 to 41% in the basin and by 16 to 19% in the delta, with lower value estimated for years 2010 to 38 and higher value for years 2070 to 99, compared with 1961 to 90 levels. In contrast, the minimum monthly flows are estimated to decline by 17 to 24% in the basin and 26 to 29% in the delta. There could be increased flooding risks during wet season and an increased possibility of water shortage in dry season.

Over-exploitation of groundwater in many countries of Asia has resulted in a drop in its level, leading to ingress of sea water in coastal areas making the sub-surface water saline. India, China and Bangladesh are especially susceptible to increasing salinity of their groundwater as well as surface water resources, especially along the coast, due to increases in sea level as a direct impact of global warming. Increasing frequency and intensity of droughts in catchment areas will lead to more serious and frequent salt-water intrusion in the estuaries and thus deteriorate surface and groundwater quality.

Droughts and floods: Global warming would cause an abrupt rise of water quantity as a result of snow or glacier melting that, in turn, would lead to floods. The duration of seasonal snow cover in alpine areas will shorten and snow cover will thaw out in advance of the spring season, leading to a decline in volume and resulting in severe spring droughts. Intense rain occurring over fewer days, which implies increased frequency of floods during the monsoon, will also result in loss of the rainwater as direct runoff, resulting in reduced groundwater recharging potential. Expansion of areas under severe water stress will be one of the most pressing environmental problems in South and South-East Asia in the foreseeable future as the number of people living under severe water stress is likely to increase substantially. Different scenarios estimate that 120 million to 1.2 billion, and 185 to 981 million people will experience increased water stress by the 2020s, and the 2050s, respectively. The gross per capita water availability in India will decline from about 1,820 m^3/yr in 2001 to as low as about 1,140 m^3/yr in 2050. India will reach a state of water stress before 2025 when the availability falls below 1,000 m^3 per capita. The decline in annual flow of Mekong River by 16 to 24% by the end of 21st century will contribute to increasing water stress.

Coastal erosion and inundation: Average global sea-level rise over the second half of the 20th century was 1.8 ± 0.3 mm/yr, and sea-level rise of the order of 2 to 3 mm/yr is considered likely during the early 21st century. The rising rates of sea level vary considerably from 1.5 to 4.4 mm/yr along the East Asia coast, due to regional variation in land surface movement. The projected relative sea-level rise is 70 to 90 cm in the Huanghe delta by the year 2050. It was reported that the regional sea-level rise over the north-western Pacific Ocean would be much more significant compared with the global average mainly due to exceptionally large warming near the entrance of the Kuroshio extension.

In Asia, erosion is the main process that will occur to land as sea level continues to rise. As a consequence, coast-protection structures will usually be destroyed by the sea while the shoreline retreats. In some coastal areas of Asia, a 30 cm rise in sea level can result in 45 m of landward erosion. Climate change and sea-level rise will tend to worsen the currently eroding coasts. The coastal recession can add up to 500 to 600 m in 100 years, with a rate of between 4 to 6 m/yr. In monsoonal Asia, decreasing sediment flux is generally a main cause of coastal erosion. Available evidence suggests a tendency of river sediment to further decline that will tend to worsen coastal erosion in Asia.

Projected sea-level rise could flood the residence of millions of people living in the low lying areas of South, South-East and East Asia such as in Vietnam, Bangladesh, India and China. Even under the most conservative scenario, sea level will be about 40 cm higher than today by the end of 21st century which will increase the annual number of people flooded in coastal populations from 13 million to 94 million. Almost 60% of this increase will occur in South Asia (along coasts from Pakistan, through India, Sri Lanka and Bangladesh to Myanmar), while about 20% will occur in South-East Asia, specifically from Thailand to Vietnam including Indonesia and the Philippines. The potential impacts of 100 cm sea-level rise include inundation of 5,763 km^2 and 2,339 km^2 in India and in some big cities of Japan, respectively. For 100 cm sea-level rise with high tide and storm surge, the maximum inundation area is estimated to be 2,643 km^2 or about 1.2% of total area of the Korean Peninsula. In China, a 30 cm sea-level rise would inundate 81,348 km^2 of coastal lowland. In Japan, an area of 861 km^2 of coastal lowland is located below high water level mainly in large cities like Tokyo, Osaka and Nagoya. A 100 cm rise in sea level could put up to 4.1 million people at risk. Damages in flooded areas are largely dependent on the coastal protection level. They can be very high such as in coastal areas of South Asia where the protection level is low. Case studies indicate that the current protection level is insufficient to protect the coasts from high sea-level rise. Further warming may lead to an increase in tropical cyclone destructive potential, and with an increasing coastal population substantial increase in hurricane-related losses in the 21st century is likely.

Deltas, estuaries and wetland: There are 11 mega-deltas with an area greater than 10,000 km^2 in the coastal zone of Asia which are home to millions of people, especially the seven mega cities that are located in these deltas. Future evolution of the major deltas in monsoonal Asia depends on changes in ocean processes and river sediment flux. Coastal erosion of the major deltas will be caused by sea-level rise, intensifying extreme events (e.g., storm surge) due to climate change and excessive pumping of groundwater for irrigation and reservoir construction upstream. Annual mean sediment discharge in the Huanghe delta during the 1990s was only 34% of that observed during the 1950s and 1970s. Saltwater intrusion in estuaries due to decreasing river runoff can be pushed 10 to 20 km further in by the rising sea level. Many mega cities in Asia are located on deltas formed during sea-level change in the Holocene period. These Asian mega cities with large populations and intensified socio-economic activities are subject to threats of climate change, sea-level rise and extreme climate event. For a 100 cm rise in sea level, half a million square hectares of Red River delta and from 15,000 to 20,000 km^2 of Mekong River delta is projected to be flooded. In addition, approximately 1,000 km^2 of cultivated farm land and sea product culturing area will become salt marshes. If abnormally high sea-surface temperatures (SST) continue to cause major bleaching events, and reduce the capacity of reefs to calcify due to CO_2 increase, most human efforts will be futile.

Air and water pollution: Climate change poses substantial risks to human health. Global burden (mortality and morbidity) of climate-change attributable diarrhoea and malnutrition are already the largest in South-East Asian countries in 2000, and the relative risks for these conditions for 2030 are expected to be the largest. In India and China, the excess mortality due to heat stress is projected to be very high, although this projection did not take into account possible adaptation and population change. There is already evidence of widespread damage to human health by urban air quality and enhanced climate variability. Throughout newly industrialized areas in Asia, air quality has deteriorated significantly and will likely contribute to widespread heat stress and smog induced illnesses in the region. The negative influence of temperature anomalies on public health has been established in Russia, and serious problems are connected with the impact of air pollution due to Siberian forest fires on human health.

A warmer and more humid climate would be favorable for propagation and invasiveness of infectious insect, and natural habitats of vector-borne diseases are reported to be expanding. Warmer water will be excellent habitats for survival and spread of infectious bacterial diseases such as cholera. Precipitation increase and frequent floods, and sea-level rise will degrade the surface water quality owing to more pollution and, hence, lead to more water-borne infectious diseases. The risk factor of climate-related diseases will depend on improved environmental sanitation, the hygienic practice and medical treatment facilities.

Population growth, migration, and development activities: The pressure on land in the 21st century will increase in Asia, due to the increasing food grain demand for the growing population, the booming economic development, as well as climate change. In the developing regions, the remaining natural flood plains are disappearing at an accelerating rate, primarily as a result of changes in land use and hydrological cycle, particularly changes in stream flows due to climatic and human-related factors. The most threatened flood plains will be those in South and South-East Asia. In some parts of South-East Asia, population growth, particularly in the uplands, continues to exert pressure on the remaining forests in the region.

In Asia, migration accounts for 64% of urban growth. Climate-related disruptions of human populations and consequent migrations can be expected over the coming decades. Periods when precipitation shortfalls coincide with adverse economic conditions for farmers (such as low crop prices) would be those most likely to lead to sudden spikes in rural-to-urban migration levels in China and India. Climatic changes in Pakistan and Bangladesh would likely exacerbate present environmental conditions that give rise to land degradation, shortfalls in food production, rural poverty and urban unrest. Such changes would likely affect not only internal migration patterns, but also migration movements to other western countries. Although food can be produced on currently cultivated land if sustainable management and adequate inputs are applied, attaining this situation would require substantial improvements of socio-economic conditions of farmers in most Asian countries to enable access to inputs and technology. The production losses due to climate change may drastically increase the number of undernourished in several developing countries in Asia, severely hindering progress against poverty and food insecurity.

Development, to a large extent, is responsible for much of the GHGs emitted into the atmosphere that drives climate change. On the other hand, development greatly contributes to reducing vulnerability to climate change and in enhancing the adaptive capacities. Rates of both total forest loss and forest degradation are higher in Asia than anywhere else in the world, because of its increasing economy and fast development in recent years. In many developing countries of Asia, small scale fuel wood collection and industrial logging for exports of timber and conversion of forests into estate crop plantation and mining are also responsible for deforestation. It is likely that climate change would aggravate the adverse impacts of forest cover loss.

Urban and financial aspects: The compounding influence of future rises in temperature due to global warming, along with local urban heat-island effects, makes cities more vulnerable to higher temperatures than would be expected due to global warming alone. It has been suggested that climate change will exacerbate the existing heat-island phenomenon in cities of Japan by absorbing increased solar radiation, leading to further increases in temperatures with negative implications for energy and water consumption, human health and discomfort, and local ecosystems. South Asia is expected to account for one-fifth of the world's total energy consumption by the end of 21st century. It is likely that climate change will influence the pattern of change in energy consumption that could have significant effects on CO_2 emission in this region.

The damages from floods, typhoons and other climate related hazards will likely increase in the future. According to the European insurer Munich Re, the annual cost of climate change-related claims could reach US $300 billion annually by 2050. The Association of British Insurers examined the financial implications of climate change through its effects on extreme storms. The projected increase in insured losses due to the most extreme storms (with current return periods of 100 to 250 years) by the 2080s would be more than twice the reported losses of the 2004 typhoon season, the costliest in terms of damage during the past 100 years. The cost of direct damage in Asia caused by tropical cyclones has increased more than five times in the 1980s as compared with those in the 1970s and about 35 times more in the early 1990s than in 1970s. These trends are likely to persist in the future.

Vulnerability of the poor: The poor, particularly in urban and urbanizing cities of Asia, are highly vulnerable to climate change because of their limited access to profitable livelihood opportunities and limited access to areas that are fit for safe and healthy habitation. Consequently, the poor sector will likely be exposed to more risks from floods and other climate-related hazards in areas they are forced to stay in. This also includes the rural poor who live in the lower Mekong countries and are dependent on fisheries as their major livelihood, along with those living in coastal areas who are likely to suffer heavy losses without appropriate protection. Protection from the social forces that create inequitable exposure to risk will be as important if not more important than structural protection from natural hazards in reducing the vulnerability of the poor.

6. ADAPTATION AND CONSTRAINTS IN ASIAN SCENES

As most mega-cities of Asia are located and substantial socio-economic activities and populations are currently highly concentrated in the coastal zones in Asia, protection from sea-level rise should remain a key focus in Asia. Future constructions should be done at elevated levels.

To assess the impact of climate change on human health, the disease monitoring system is essential as the basic data source. The monitoring of diseases should be done along with related ecological factors, because the relation between weather factors and vector- borne diseases are complicated and delicate. Disease monitoring is necessary in assessing the effectiveness and efficiency of the adaptation measures. Implementation of heat watch and warning system will likely be helpful in reducing the impacts of climate change on human health.

Rapid population growth, urbanization and weak land-use planning and enforcement are some of the reasons why poor people move to fragile and high-risk areas which are more exposed to natural hazards. Moreover, the rapid growth of industries in urban areas has induced rural-urban migration. Rural development together with networking and advocacy, and building alliances among communities is a prerequisite for reducing the migration of people to cities and coastal areas in most developing countries of Asia.

Effective adaptation and adaptive capacity in Asia, particularly in developing countries, will continue to be limited by low level of awareness among decision makers of the local and regional impacts of the impacts of climate change and responses of natural systems to climate change. Poverty is identified as the largest barrier to developing the capacity to cope and adapt. The poor usually have a very low adaptive capacity due to their limited access to information, technology and other capital assets which make them highly vulnerable to climate change.

It is very likely that in countries of Asia facing serious domestic conflicts, pervasive poverty, hunger, epidemics, terrorism and other pressing and urgent concerns, attention may be drawn away from the dangers of climate change and the need to implement adaptation. The existing legal and institutional framework in most Asian countries remains inadequate to facilitate implementation of comprehensive and integrated response to climate change in synergy with the pursuit of sectoral development goals. It is important to mainstream climate change into development planning at all scales, levels and sectors.

Coupled with illiteracy, poverty subverts the ability of the people to pursue the usually long-term sustainable development goals in favor of the immediate goal of meeting their daily subsistence needs. With climate change, the poor sectors will be most vulnerable and, without appropriate measures, climate change will likely exacerbate the poverty situation and continue to slow down economic growth in developing countries of Asia.

Rapid economic growth characterized by increasing urbanization and industrialization in several countries of Asia will likely drive the increase in the already high demand for raw materials such as cement, wood, steel and other construction materials in Asia. Consequently, the use of forests, minerals and other natural resources will increase along with the increase in carbon emission. The challenge here is finding the development pathways wherein GHG emission is minimized while attaining high economic growth. Equally vital in this regard is the promotion of equity in spreading the benefits that will arise from economic growth so as to uplift the condition of the poor sector to a state of enhanced capacity to adapt to climate change. Another concern related to economic growth is that use of land for farm-agricultural purposes is becoming to be considered less profitable than for industrial and commercial purposes. In the absence of appropriate regulatory intervention, this can undermine the production of adequate food supply and further jeopardize the access of the poor to food support.

Sustaining economic growth in the context of changing climate in many Asian countries will require the pursuit of enhancing preparedness and capabilities in terms of human, infrastructural, financial and institutional dimensions with the aim in view of reducing the impacts of climate change on the economy. For instance, in many developing countries, instituting financial reforms could likely result in a more robust economy that is likely to be less vulnerable to changing climate.

REFERENCES

Climate Change 2007 – *The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Cambridge University Press.

Climate Change 2007 – *Impacts, Adaptation and Vulnerability*, Contribution of Working Group Ⅱ to the Fourth Assessment Report of the IPCC, Cambridge University Press.

Climate Change 2007 – *Mitigation of Climate Change*, Contribution of Working Group Ⅲ to the Fourth Assessment Report of the IPCC, Cambridge University Press.

Climate Change 2007 – *Synthesis Report*, Cambridge University Press.

News Release: *The Warmest Global Mean Surface Temperature Observed for March to May 2010*, Japan Meteorological Agency, 15 June 2010.

Promotion systems for PP-band retrofitting of weak masonry houses in developing countries

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ABSTRACT

Seismic retrofitting of vulnerable masonry houses is the key to reduce earthquake damage – especially casualties – in developing countries. However, retrofitting has not been promoted mainly due to lack of economic resources. In this paper, four seismic retrofitting promotion systems, making use of insurance and microfinance, were proposed and validated. Systems were proposed based on the correspondence analysis of 83 masonry houses' data, and were validated by using earthquake risks and fragility function. Results showed the economic effect for the stakeholders in each promotion system, for 25 earthquake risk levels and four masonry structure types, which therefore can be used as an index for seismic retrofitting promotion.

Keywords: *PP-band method, seismic retrofitting, socio-economic conditions, incentive systems, earthquake insurance*

1. INTRODUCTION

Seismic retrofitting of low earthquake-resistant houses is essential to reduce both human and economic losses in earthquake disasters. However, in developing countries, lack of economic resources is a critical issue to promote seismic retrofitting. Therefore, a cheap and easy retrofitting method utilizing PP-bands has been proposed in Meguro laboratory as a locally acceptable and available solution (Mayorca & Meguro, 2003; Meguro, 2006). The retrofitting cost is approximately 30 US$ per housing unit if installed by the house owners. In case of hiring masons, the cost will still be no more than 5% of the total building cost. However, in many parts of the world, this amount of money may still be unaffordable.

To solve the issues above, previous studies have proposed a two-step incentive system by the government for promoting PP-band retrofitting for masonry houses (Iritani et al, 2008). The first step of this system is to provide materials for retrofitting and a subsidy, which is given after the house has been checked to be retrofitted properly. This subsidy is for preventing the house owners from selling the provided materials and to give an incentive to retrofit. The second step is to give compensations to those whose houses were damaged due to earthquake in spite of retrofitting. The validation showed if this two-step incentive system was implemented before the 2003 Bam, 2005 Kashmir and 2006 Java earthquakes, the expenditure of the government for compensation for the people whose houses were damaged would have been decreased by 95.8%, 81.4% and 75.6%, respectively, as well as decreasing human fatalities by at least 80% to 90% in all cases. However, in this system, the remaining problems are the funding source that government should prepare for the initial cost and proper prioritization by the government on the selection of the area and houses to which this system is applied.

This study aims to propose some systems that can solve these problems to promote seismic retrofitting, focusing on the economic aspect of the stakeholders.

2. ANALYSIS OF MASONRY HOUSES

Masonry houses have been divided by structural details in the previous studies; however, little attention has been paid to the social details. To promote retrofitting by making use of the cheapness and simplicity of PP-band retrofitting method, the economic situation of the residents and the construction situation of the houses must be analyzed.

Data on the economic situation of the residents and the construction situation of 83 masonry house samples were collected from the World Housing Encyclopedia (EERI, 2009), and correspondence analysis was done. Table 1 shows the categories for each sample.

Table 1: Categories of masonry houses

Housing condition	Building cost : annual income	Resident's financing	Construction process	Insurance
1. Single family	7. 5:1	11. Owner finance	17. Engineered	21. Insured
2. Multi family	8. 4:1	12. Personal saving	18. Non-engineered	22. Not insured
3. Urban	9. 3:1	13. Informal network	19. Code	
4. Rural	10. 1:1	14. Microfinance	20. No code	
5. With modification		15. Commercial bank		
6. Without modification		16. Government owned		

From the correspondence analysis, masonry houses were grouped into four groups, i.e. Urban, Semi-urban, Rural, and Microfinance (MF) groups as shown in Figure 1. In the figure, the horizontal axis shows the construction conditions and the vertical axis shows the economical situation by ratio of building cost to annual income. Cases with relatively good conditions are located on the right hand side and relatively expensive houses are located in the upper part of the figure.

The Urban group has relatively sufficient construction and economic situations, such as the role of engineer and architect during the construction, code enforcement and access to commercial banks or insurance. In addition, the ratio of building cost to annual income is about 5:1, which means they live in relatively expensive houses. On the other hand, the Semi-urban group does not have access to insurance due to lack of economic resources. Their ratio of building cost to annual income is about 4:1. The Rural group does not have sufficient construction or economic situation. Informal extensions of houses are seen, and residents usually do not have any access to commercial banks or insurance, so they rely on personal savings or owner financing. Their ratio of building cost to annual income is about 1:1. On the other hand, some of them are making use of microfinance (MF group). For the MF group, the ratio of building cost to annual income is about 5:1. However, this means that their annual income is very low, which also explains why they are using microfinance.

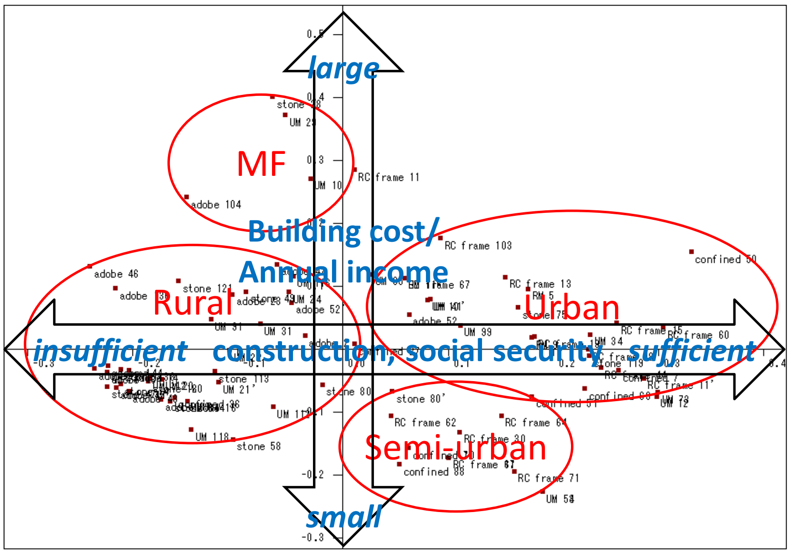


Figure 1: Grouping of masonry houses

After considering the categorization explained above, we proposed appropriate retrofitting promotion systems to each group considering the economic and social situations, as shown in Table 2.

Table 2: Proposed promotion systems for each masonry category

Masonry Type	Proposed promotion system
Urban Group	Micro Earthquake Insurance (MEI) based Promotion System
Semi-urban Group	Government Micro Earthquake Reinsurance based Promotion System I (GMER I)
Rural Group	Government Micro Earthquake Reinsurance based Promotion System II (GMER II)
MF Group	Micro Credit based Promotion System (MC System)

3. PROPOSAL OF SEISMIC RETROFITTING PROMOTION SYSTEMS

In the following proposed systems, premium is either set at a low price or none by making use of micro insurance and microfinance. Also, these systems are designed for all stakeholders to each have their own benefits, as introduced below. In each system, three kinds of workers for retrofit are considered, i.e. self-retrofitting by the house owners themselves, by local masons, and by PP-band method-licensed masons. Although we considered these three subsystems, only the self-retrofitting model is introduced here due to space limitation.

3.1 Micro Earthquake Insurance based Promotion System (MEI System)

In this system, residents who have performed PP-band retrofitting using materials provided freely by the insurance companies will be insured, and when their houses are damaged due to earthquake, they will receive insurance money worth their house rebuilding cost. The premium will include the retrofitting cost and insurance money, but since PP-band retrofitting is cheap and the damage can be reduced drastically, the premium can be set at a low price. The insurance premium was estimated in the validation.

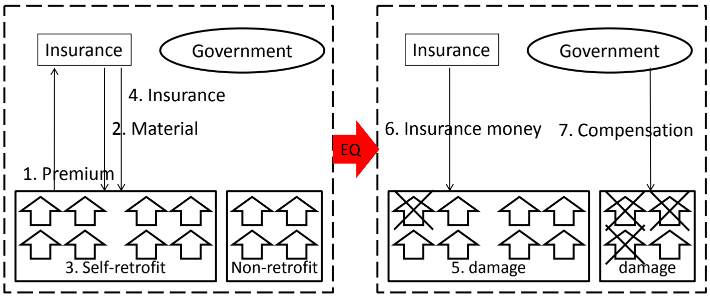


Figure 2: Micro Earthquake Insurance based Promotion System (MEI System)

3.2 Micro Earthquake Government Reinsurance based Promotion System I (MEGR I)

This system is basically the same as the MEI System, but the premium will be lower because it will not include the retrofitting cost. Insurance companies will bear the retrofitting cost at the initial stage and collect the cost back from the government when an earthquake occurs. The insurance premium was estimated in the validation.

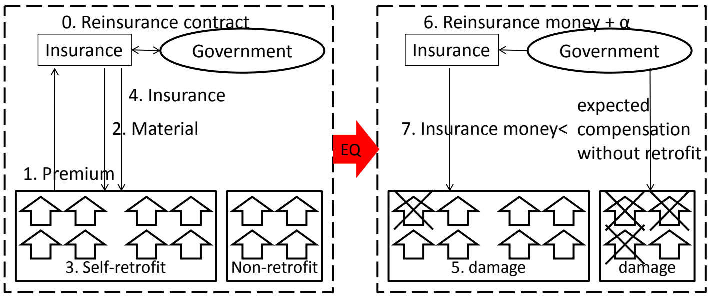


Figure 3: Micro Earthquake Government Reinsurance based Promotion System I (MEGR I)

3.3 Micro Earthquake Government Reinsurance based Promotion System II (MEGR II)

In this system, the insurance companies will bear the retrofitting cost and the residents will be insured. Insurance companies will receive reinsurance money from the government and collect retrofitting cost and insurance money for residents, together with their profit. Reinsurance money will be paid within the range of the amount of compensation money which was reduced for damaged people due to retrofitting, which can be considered as government's benefit. The insurance money for residents and profit for insurance companies were estimated in the validation.

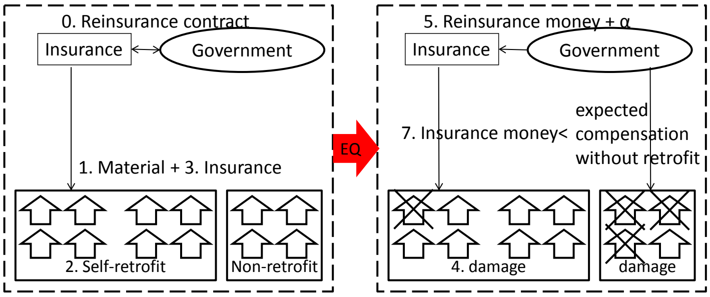


Figure 4: Micro Earthquake Government Reinsurance based Promotion System II (MEGR II)

3.4 Microfinance based Promotion System (MF System)

In this last system, MFIs (Microfinance Institutes) will collect retrofitting cost through investment and perform retrofitting. Residents who have performed retrofitting will receive micro credit loan as an incentive. MFIs will collect insurance money from the government, collect outstanding loan balance, and also give return to the investors. For the investors, this extra dividend will be an incentive to invest, as well as the clear social contribution in terms of earthquake disaster mitigation. The expected amount of collection on outstanding loan balance for MFIs and ROI (rate of return) per investment (= retrofitting cost) were estimated in the validation.

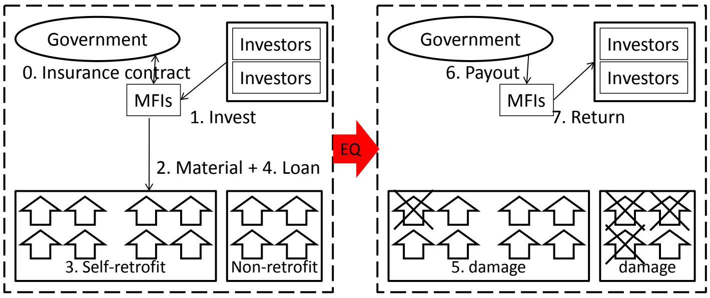


Figure 5: Microfinance based Promotion System (MF System)

4. VALIDATION OF THE PROPOSED SYSTEM

Validation focused on the economic aspects of the stakeholders in each system. First, earthquake risk was defined at 25 levels as shown in Figure 6. Second, fragility functions were used to estimate the earthquake damage for each earthquake risk. Fragility functions of 1) adobe and/or mud, 2) brick and/or stone, 3) brick 1-2F, 4) brick 3F and 5) concrete block houses were used for comparative study among the different structures. For PP-band retrofitted structures, 1) self-retrofit (retrofitted by house owners), 2) local mason-retrofit (retrofitted by local masons) and 3) licensed-retrofit (retrofitted by PP-band licensed masons) were used, considering upper (+) and lower (-) bounds. Finally, the economic effects for the stakeholders were estimated for each system. The results shown below are for each structure type in the case of self-retrofitting.

JMA	PGV [cm/s]	50 years exceedance probability (return period) 2% (2745 yrs)	5% (975 yrs)	10% (475 yrs)	39% (100 yrs)	62% (50 yrs)
4	8.1					
5-	16			Kashmir		
5+	31			Java		
6-	60		Kashiwazaki	Tokyo		
6+	116				Shizuoka	

Figure 6: Earthquake risk

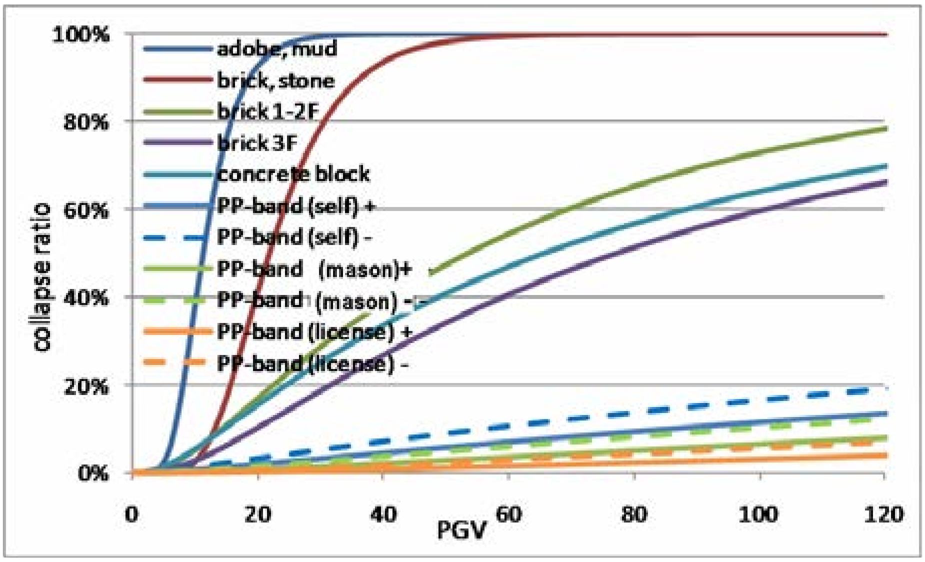
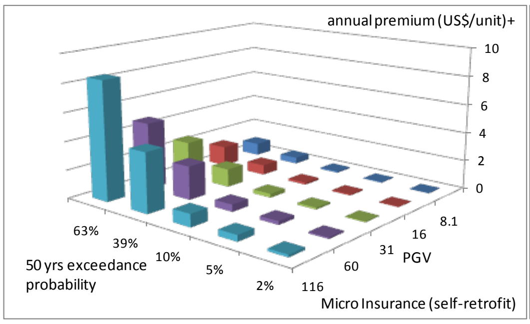


Figure 7: Fragility functions (JICA, 2005 & JICA and IMM, 2002)

Table 3: Costs used for analysis

Building cost (US$)	Retrofitting cost (US$) Self-retrofit	by local mason	By licensed mason
3,000	30	150(30+120)	270(30+120x2)



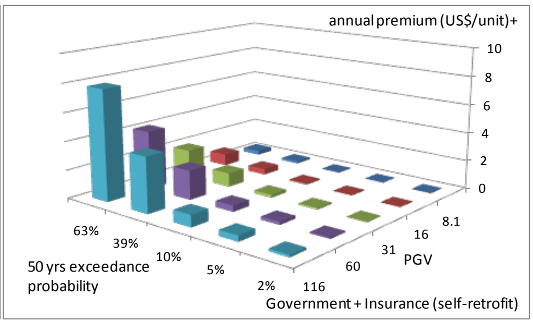


Figure 8: Premium for MEI system

Figure 9: Premium for GMER I system

Table 4: Comparison of the earthquake insurance

	Japan	California	New Zealand
Premium rate (%)	0.50-3.15	0.46-8.05	0.50
Insurance money limit (US$)	550,000	100,000	61,000

The annual premium was estimated to be less than 10 US$ at all 25 earthquake risk levels under the condition that residents will receive insurance money equal to the building cost. Compared to the other earthquake insurances in the world, as shown in Table 4, this system is valuable to the residents.

Insurance money for residents was more than 2,000 US$ per year at high earthquake risk levels. If the contract is made for 10 years, insurance money will be 20,000 US$, which is sufficient for rebuilding a house. For insurance companies, annual profit by reinsurance money was estimated, which was in the positive for all earthquake risk levels. This means that this system has an incentive to both the residents and the insurance companies. Furthermore, insurance companies have a chance to spread insurance to low income people by this system.

When we calculated the amount of collection on outstanding loan balance for MFIs, it became positive at all earthquake risk levels. In addition, ROI (rate of return on investment) per investment (= retrofitting cost) was estimated to be positive at all earthquake risk levels. For the MFIs, this means they may be able to collect their outstanding loans within less than 10 years in most cases, as shown in Table 5.

5. CONCLUSIONS

To promote seismic retrofitting of low earthquake-resistant houses by PP-band retrofitting method, four promotion systems for seismic retrofitting implementation were proposed and validated for their economic effects. With the Micro Earthquake Insurance (MEI) based Promotion System and the Government Micro Earthquake Reinsurance based Promotion System I (GMER I), the annual premium was estimated to be no more than 10 US$ per unit at 25 different earthquake risk levels. With the Government Micro Earthquake Reinsurance based Promotion System II (GMER II), insurance money was enough to rebuild a house, even at relatively high earthquake risk levels. In addition, profit for insurance companies was estimated under the condition that residents will receive insurance money sufficient for reconstruction. With Micro Credit (MC) based Promotion System, the amount of collection on outstanding loan for MFIs, and ROI for investors were estimated, both of which proved to be in the positive. Furthermore, validation was done for five different structures and three different retrofitting conditions, which allows consideration of implementation in areas with combined structures. Therefore, we conclude that this study has proposed effective promotion systems, together with an index for implementation.

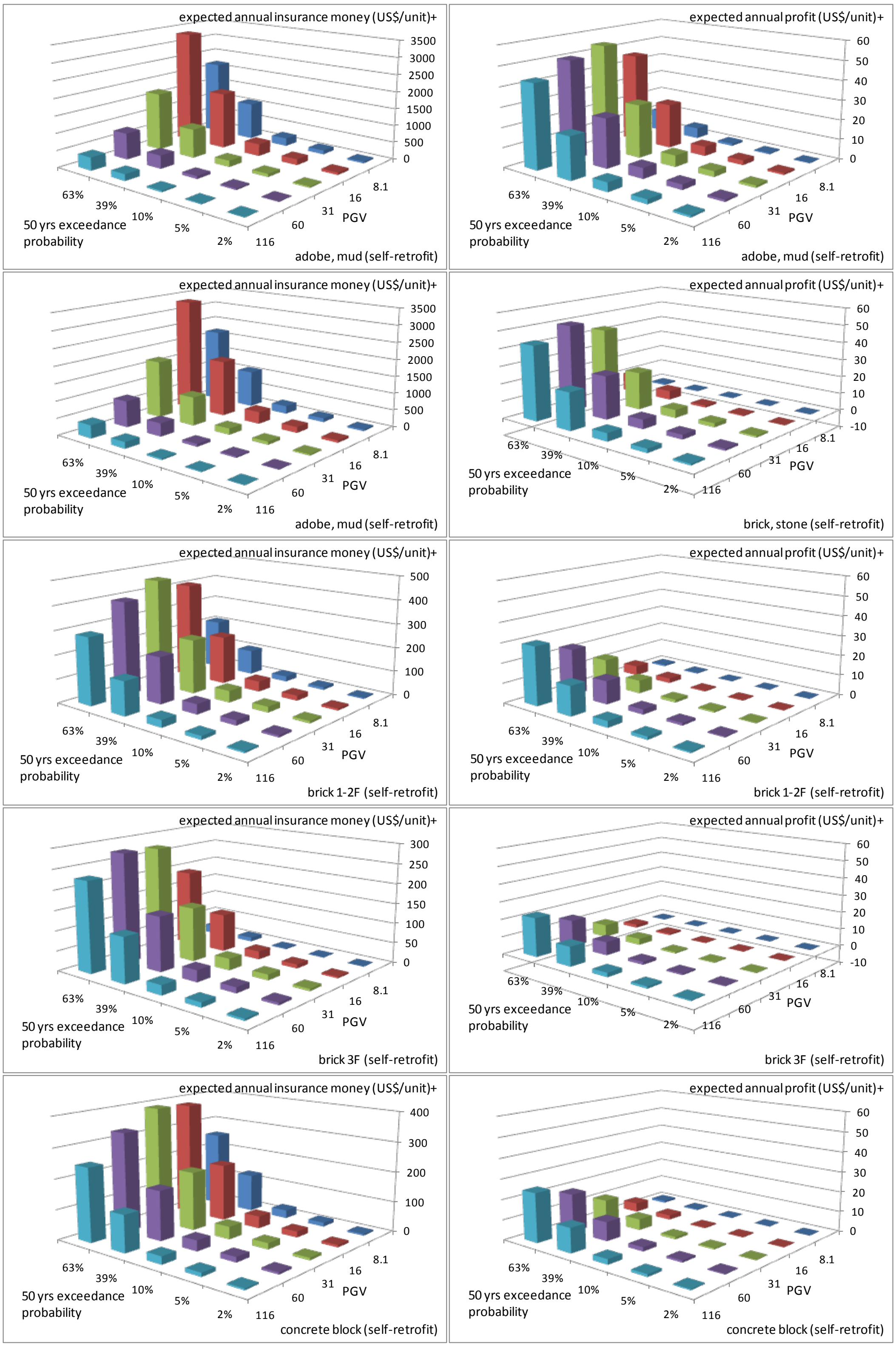


Figure 10: GMER II system (left: insurance money, right: profit)

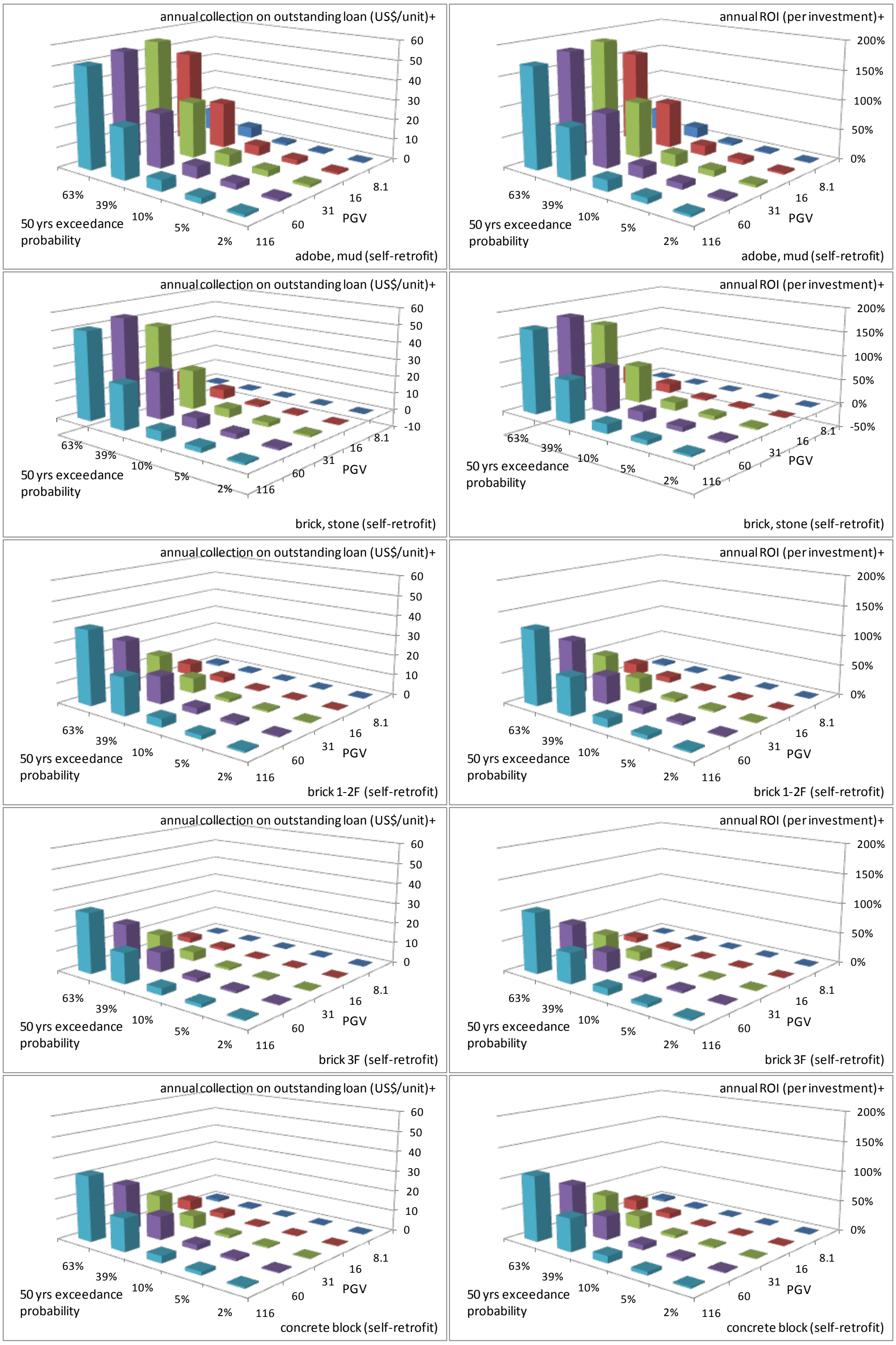


Figure 11: MF system (left: collection on outstanding loan, right: ROI)

Table 5: Amount of the outstanding loan
(Microfinance Information Exchange, 2008)

	2005 (US$)	2006(US$)	2007(US$)
Africa	174	241	325
Asia	120	139	164
ECA	1,127	1,404	1,931
LAC	642	684	848
MENA	241	264	345

REFERENCES

Earthquake Engineering Research Institute and International Association for Earthquake Engineering (2009). "World Housing Encyclopedia", http://world-housing.net/

Iritani, S., Mayorca, P., and Meguro, K. (2008). "Proposal of a system to promote retrofitting of vulnerable masonry houses in developing countries." *Bulletin of Earthquake Resistant Structure Research Center*, No. 41, 55-60.

Japan International Cooperation Agency (2005). "The Study on Seismic Microzoning of the Greater Teheran Area in the Islamic Republic of Iran."

JICA and IMM (2002). "The Study on A Disaster Prevention/Mitigation Basic Plan in Istanbul including Seismic Microzonation in the Republic of Turkey."

Meguro, K. (2006) "Damage to non-engineered structures due to the 2005 Northern Pakistan Earthquake and development of low cost and feasible retrofit method for masonry structures." *Journal of Japan Society for Natural Disaster Science*, No. 25-3, 381-392.

Microfinance Information Exchange (2008), Micro Banking Bulletin: 2005-2007 benchmarks.

P.Mayorca and K.Meguro (2003), Proposal of a new economic retrofitting method for masonry structures, *Proc. of the 27th JSCE Symposium of Earthquake Engineering.*

DIAGNOSIS OF THE SEISMIC VULNERABILITY OF BUILDINGS AT DHAKA USING NON-DESTRUCTIVE TESTING

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ABSTRACT

Bangladesh has been identified as a moderate earthquake vulnerable country according to the World Seismic Map. The frequency of earthquake occurrence points to the probability of facing a serious seismic hazard. Unfortunately, from the studies performed in six important locations of Dhaka city the discrepancy between seismic design according to Bangladesh National Building Code and the surveyed buildings at different areas in the capital of Bangladesh has been observed. Furthermore, infrastructure construction by land fill has been marked as the potential risk for seismic hazard due to liquefaction of these reclaimed soils. In addition, some buildings are found to be risky due to the unavailability of appropriate building documents. All these factors are clearly jeopardizing to the overall safety of Dhaka city.

The main objective of the paper is to ascertain the details survey of building including the dimension of structural elements, structural irregularities and reinforcement detailing which consists of spacing, bar number, clear cover for beam, column and slab. Basically two non-destructive testing, Ferroscan measurement and microtremor observations have been executed in order to collect data. Ferroscan is used to obtain reinforcement diameters and location within the RC buildings and MICROTREMOR has been used to determine the natural frequency of the Buildings. Some major findings are obtained from the analysis of the surveyed data. Most of the buildings do not have proper reinforcement arrangement, lack anti seismic design etc. In a few cases, the natural frequency of building is close to that of soil. There is a possibility of resonance. Seismic vulnerability of a few studied buildings has also been evaluated based on the Provision of Japanese RC Building Seismic Evaluation criteria. It shows the same threatening condition as found from the non-destructive testings. It can be said that if the effective step is not taken right now the people of Dhaka city may suffer greater seismic risk, in which most of the faulty building may collapse.

Keywords: seismic hazard, retrofitting, structural element, natural frequency

1. INTRODUCTION

The purpose of this study is to analyze the seismic vulnerability of buildings at various locations in Dhaka city. In order to do this, checking structural elements in light of seismic design and analysis of resonance phenomena between building and soil on the basis of natural frequency has been executed. Therefore, two non-destructive tests have been carried out in this project. In addition, the seismic evaluation of buildings according to the first level of screening procedure of the Japanese RC building seismic evaluation provision has also been performed.

Ferroscanner, the electromagnetic detector to record image of reinforcements in concrete up to 100 mm depth, is the efficient device for the identification of reinforcement if there is no found basic design document or having contradiction to design in this building. Column and Lift Core are the most important elements in any structural system. This is why the above two structural elements along with slabs have been surveyed properly using Ferroscanner. In this survey, detection of reinforcement includes number of reinforcement, spacing of reinforcement, bar number and cover over the reinforcement. Eighty three buildings have been selected at six locations in Dhaka city as shown in Figure 1. These are Old Dhaka, BUET campus, Lalmatia, Mirpur, Banani and Uttara.

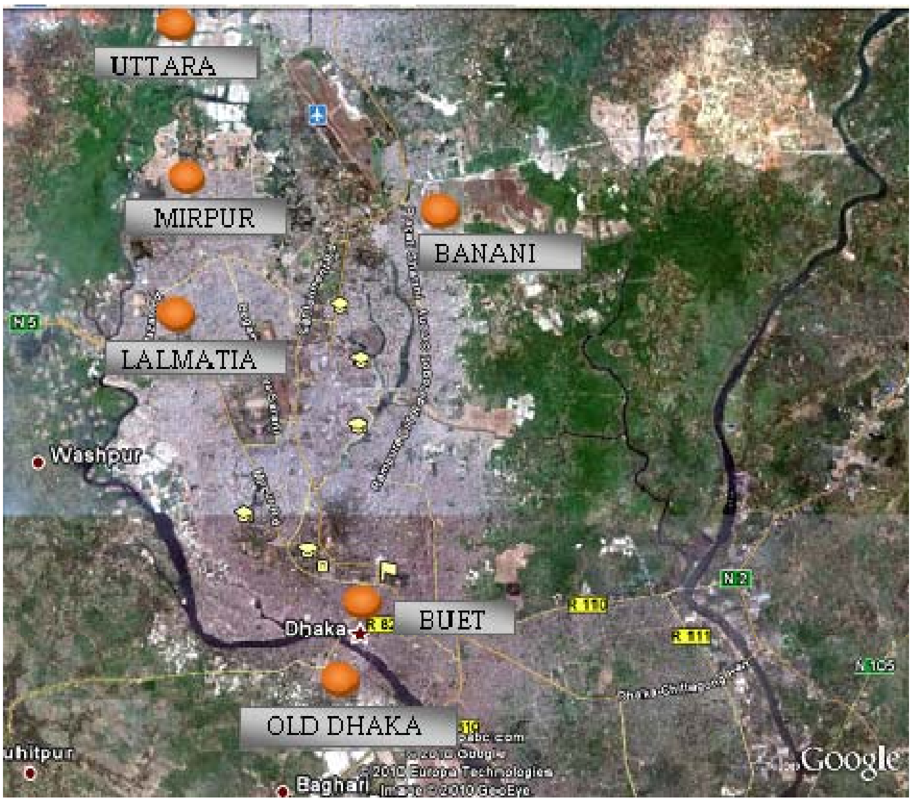


Figure 1: Survey site at Dhaka city (Source: Google map)

In addition, Microtremor is also used to record the fundamental frequency and period of those buildings and soil. The dynamic properties are the important factor for seismic design. Response of building mainly depends on the characteristics of both excitation forces and dynamic properties of buildings. This is why the natural frequency and period is taken on the top of the roof of those building to identify the dynamic properties of buildings. Furthermore, the vibration characteristics in soil are different from building. Hard soil gives high frequency and soft soil gives low frequency. A structure may experience a vibration period at which it oscillates in the earthquake vibration motion and will tend to response to that. Natural frequency of structure is obtained based on the spectral ratio of horizontal component of the building to that of ground. Meanwhile, practical application of Microtremor in the field of engineering has advanced tremendously. One of the powerful and simplest applications of Microtremor observation is in seismic micro zoning (see Figure 2).

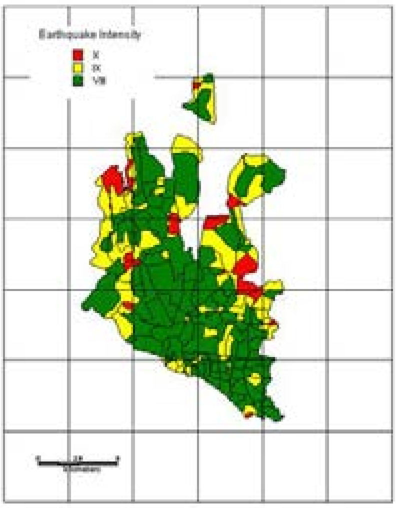


Figure 2: Seismic Microzonation Map for Dhaka City
(after Rahman, 2004)

From the data analysis of these building, most of the building are vulnerable due to moderate seismic activity. In Old Dhaka, the majority of buildings are not constructed according to proper seismic design code. Some of these buildings are likely to be damaged because of lower intensity of earthquake. In BUET campus, about twenty nine buildings natural period are not close to that of soil. So, they are out of danger of resonance and natural period of the remaining twenty one buildings are close to that of soil, so their seismic response can be considerably amplified. Results obtained from Ferroscan are not satisfactory. Variation of cover and spacing of lateral ties in columns and stirrups in beam from design are above acceptable limit. The buildings of three places like Lalmatia, Mirpur and Uttara are vulnerable due to medium seismic force. There is a significant variation in reinforcement in those buildings. Some of them are vulnerable due to resonance.

2. CHECKING OF STRUCTURAL ELEMENTS USING FERROSCAN

Ferro-scanner, which detects reinforcements in concrete, is efficient device for the detection of structural elements in a concrete building. There are many methods for the diagnosis of the rebar arrangement like Electromagnetic method, X-ray measurement, and High energy X-ray CT Scan and Radar inspection. In our survey, Electromagnetic method in Ferroscanner has been utilized in the surveyed building.

When electric current run through a coil of the apparatus, magnetic field is formed. Electric current is produced in the reinforcement bar because of the magnetic field. The field induces electric current in the secondary coil to be measured. When electric current runs through a coil of the electro-magnetic sensor, magnetic flux is measured. Electromotive force of coil changes due to magnetic flux. Thickness of clear cover or diameter of the reinforcement bar can be estimated from magnetic flux change. Induced magnetic field depends on the distance between sensor and reinforcement. When bars are too close, it becomes difficult to identify the numbers of bar. The rebar detection ranges usually 120-150mm depending on bar size and maximum depth is 180mm. Depth measurement ranges 100-140 mm depending in bar size. However, depth accuracy is ±2.5 mm for most bars at common depth.

The Hilti PS 200 is a system used for high-end reinforcement detection. The important elements of the system are the scanner, the monitor and the software. Scanner (PS 200 S) is used to scan the reinforced concrete element whereas Monitor (PS 200 M) is used to show the bar and to analyze on site (see figure 3(a)).

For Ferroscan observation the team identified the column and marked them in drawing as well as in the structural part of the building. Then they scan it carefully with the scanner and store the data. The collected raw data were analyzed with help of the Ferroscan software. Sometimes hardboard has been used to execute the scan efficiently. Figure 3(b) shows the process of Ferroscan and the reinforcement data in Villa Vatia.

Figure 3(a): PS 200 Ferroscan system

Figure 3(b): Column and slab checking using Ferroscan

3. MICROTREMOR OBSERVATION

For Microtremor observation, sensors have been fixed on the floor of building at the beginning. The sensor has been placed on the basis of long side and short side of building. Three sensors have been located at different places to find out structural stiffness and natural period. One sensor has been fixed at the top of the building, one at the free field near the building and other at any floor level of building. In this survey, approximately 60,000 data points with sampling frequency 100 have been recorded. Sometimes observation of the two building has been taken to save time. After taking the observation with the help of a program the time domain velocity data is converted to frequency domain data and find out the natural period of the buildings. Microtremor measurement instrument is shown below in Figure 4.

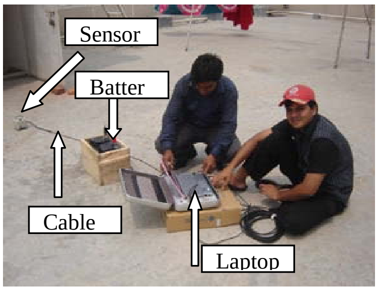
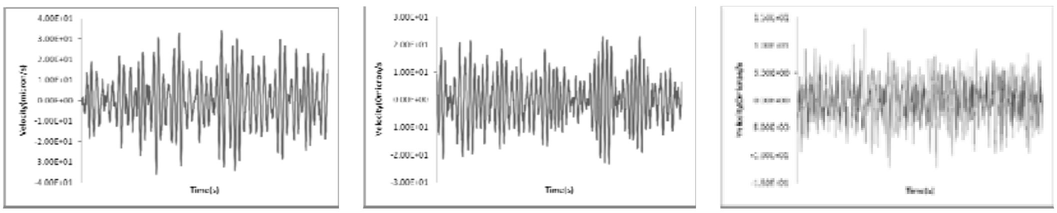


Figure 4: Microtremor data recording at Ameralo, Banani

Soil characteristics can be assessed by Microtremor measurement. Hard soil gives high frequency and soft soil gives long period. A structure may experience a vibration period at which it oscillates in the earthquake vibration motion and will tend to response to that. Natural frequency of structure is obtained based on the spectral ration of horizontal component of the building to that of ground. The velocity time histories along three directions and Fourier spectrums at different time interval in KING SHOPTAK RAJONIGANDA (MIRPUR) are shown in Figures 5 and 6 respectively.



X-direction Y-direction Z-direction

Figure 5: Velocity time history at X, Y and Z directions

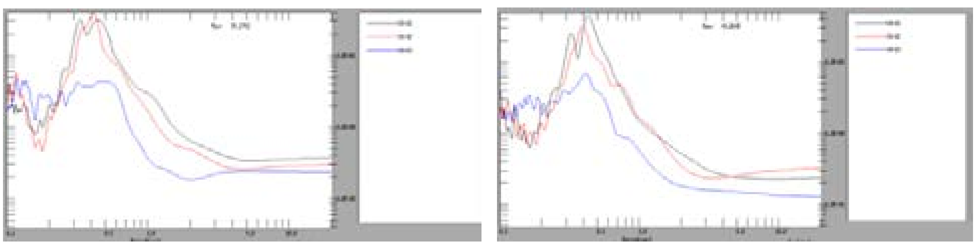


Figure 6: Fourier spectrums of two time intervals of 20 seconds each (from 90 to 110 seconds and from 400 to 420 seconds)

Wave propagation mechanism of Microtremor and its relation with ground vibration characteristics were studied from the beginning of Microtremor studies (Aki, 1957; Kanai and Tanaka, 1961). There are two types of Microtremor observations. These are point and array observations of microtremors (Ansary et al., 1996). From the array observation of Microtremor of period greater than 1 sec, Rayleigh-wave and Love-wave originating from natural sources, such as sea wave, variation of air and wind pressure can be recognized. On the other hand, short-period Microtremor of period less than 1 sec is thought to be generated by artificial noises such as traffic vehicles, industrial plants, household appliances, etc. Some researches (Sato et al., 1991; Tokimatsu and Miyadera, 1992; Tokimatsu et al., 1994) have showed that microtremors are mainly composed of Rayleight-wave and some (Nakamura, 1989; Wakamatsu and Yasui, 1995) have showed that short-period Microtremor bears resemblance to shear-wave characteristics. Nevertheless, Microtremor can also be dominated by Love–wave (Tamura et al., 1993). Recently, Suzuki et al. (1995) have applied Microtremor measurements to the estimation of earthquake ground motions based on a hypothesis that the amplitude ratio defined by Nakamura can be regarded identical with half of the amplification factor from bedrock to the ground surface. However, the real generation and nature of microtremors have not yet been established.

4. **DATA ANALYSIS**

In this study, about eighty three buildings have been checked on various points of view, such as structural element checking using Ferroscan, resonance and stiffness criteria using Microtremor, and the first level of screening procedure of Japanese RC building seismic evaluation provisions (2001).

Table 1 shows the probability of resonance in surveyed places. On the other hand, Table 2 gives the structural vulnerability of building on the basis of Ferroscan. In addition to these, Table 3 and Table 4 represent Seismic index of structure I_S and of non-structural elements I_N. The most of the building in BUET campus are vulnerable in consideration of resonance because the predominant period of these buildings is close to that of the soil. However, some of them are unlikely to cause resonance phenomena. But there is structural disparity from various points of view in according to our National Building Code (BNBC, 1993). The building has major structural irregularities such as soft story, re-entrant corner, torsional irregularity, soft story and story mass irregularity. Moreover, variation of clear cover is high. Spacing of lateral ties in column is not as per code.

The buildings in Old Dhaka are likely to be occurred severe seismic hazard. Most of the building, residential as well as religious purposes, is not built according to BNBC (1993). In those areas, resonance phenomena are not analyzed, but, structural vulnerability has been investigated properly. Variation of clear cover is high in most of the building. Spacing of lateral ties in column is not as per code. But, there are a few buildings in those areas which are quite good in consideration of seismic activities. However, majority of the buildings are vulnerable not only for the seismic activity, but also fire or any other hazard.

The building in others areas, like Banani, Mirpur, Lalmatia and Uttara, are vulnerable due structural irregularity as well as resonance. But, there are a few buildings in those areas which are quite good in consideration of two important seismic activities. Furthermore, the construction quality of those buildings is not very well. Some buildings are not constructed according to our National Building Code.

Table 1: Predominant period of buildings from Microtremor observations

Building Name and Location	**Storey of Building**	**T= N/10**	**Observed period (sec)**		**Site period (sec)**		**Probability of Resonance**
			X-direction	Y-direction	X-direction	Y-direction	
AMARELO H#77/B, R#3, BLOCK #F, BANANI	6	0.6	0.44	0.35	0.2	0.2	No
King Shoptak Rajoniganda, 2 2/C, AVENUE-3, PLOT-3, HAZI ROAD, MIRPUR-2	7	0.7	0.34	0.45	0.25	0.25	No
MI-NIBASH H# 1/3, R#19,BLOCK#B, SECTION #10, MIRPUR, DHAKA-1216	9	0.9	0.32	0.39	0.30	0.30	YES
NHB 15/3, Ibrahimpur,Mipur-14	6	0.6	0.41	0.43	0.30	0.30	No
RIDGE VALLEY H#29, R#7, BLOCK#F, BANANI MODEL TOWN	10	1	0.51	0.30	0.25	0.25	No
VILLA VATIA H#3/8, BLOCK#E,LALMATIA, DHAKA-1207	7	0.7	0.35	0.37	0.20	0.20	No
SUVASTU SARINA H#1/4,BLOCK#F,LAL-MATIA, DHAKA-1207	8	0.8	0.31	0.43	0.20	0.20	No
TOTAL GODHULI PLOT-16, SECTOR-10, ROAD-11, UTTARA R/A, DHAKA	6	0.6	0.5	0.3	0.26	0.26	YES
IFCDR Building, BUET	4	0.4	0.5	0.5	0.7	0.65	No
Eleven Storey Tower Building, BUET	11	1.1	0.4	0.4	0.3	0.3	No
Civil Engineering Building, BUET	7	0.7	0.26	0.39	0.5	0.33	No
EME Building, BUET	7	0.7	0.37	0.37	0.25	0.25	YES
Library Building, BUET	5	0.5	0.33	0.36	0.25	0.26	No
Architecture Building, BUET	5	0.5	0.26	0.38	0.4	0.4	YES
URP Building, BUET	5	0.5	0.27	0.3	0.4	0.4	YES
ARC Building, BUET	5	0.5	0.18	0.3	0.5	0.26	No
New Academic Building, BUET	12	1.2	0.27	0.18	0.32	0.35	No
Controller of	5	0.5	NA	NA	0.3	0.35	YES

Building Name and Location	Storey of Building	T= N/10	Observed period (sec)		Site period (sec)		Probability of Resonance
			X-direction	Y-direction	X-direction	Y-direction	
Examination building, BUET							
Engg. University School Building, BUET	4	0.4	NA	NA	NA	0.52	YES
Titumir Hall, BUET	4	0.4	0.24	0.27	0.38	0.52	NO
Sher-e-Bangla Hall, BUET	4	0.4	0.32	0.27	0.38	0.31	YES
Dr. M.A. Rashid Hall, BUET	4	0.4	0.32	0.32	0.32	0.38	YES
Building Number 47 BUET	6	0.6	0.39	0.34	0.38	0.32	YES
Building Number 62 BUET	6	0.6	0.32	0.28	0.3	0.3	YES
Fire Service Station (Head Office, Dhaka) BUET	6	0.6	0.4	0.38	0.3	0.3	YES
Ban Bhaban Main Building, BUET	5	0.5	0.3	0.3	0.3	0.23	YES
Fire Service Station, Lalbag, BUET	4	0.4	0.27	0.25	0.07	0.06	YES
Shahid Smirity Hall middle Building, BUET	4	0.4	0.3	0.28	0.18	0.07	YES
Shahid Smrity Hall north Building, BUET	5	0.5	0.2	0.2	0.32	0.3	No

Note: X = Long direction and Y = Short direction

Table 2: Data analysis (Ferroscan)

Building Name and Location	Adequacy of Reinforcement			Structural Vulnerability
	Column	Slab	Beam/shear wall	
TEACHERS' QUARTER 47/1-6, BUET campus	not ok	ok	not tested	moderate
AMARELO H#77/B, R#3, BLOCK #F, BANANI	ok	ok	not tested	moderate
King Shoptak Rajoniganda, 2/C, AVENUE-3, PLOT-3, HAZI ROAD, MIRPUR-2	not ok	ok	not tested	moderate
MI-NIBASH H# 1/3, R#19,BLOCK#B, SECTION #10, MIRPUR, DHAKA-1216	not ok	not ok	not tested	high
NHB 15_3 15/3, Ibrahimpur,Mipur-14	not ok	not ok	not tested	high
RIDGE VALLEY H#29, R#7, BLOCK#F, BANANI MODEL TOWN	ok	ok	not ok	moderate
VILLA VATIA H#3/8, BLOCK#E, LALMATIA, DHAKA-1207	not ok	ok	not tested	moderate

Building Name and Location	**Adequacy of Reinforcement**			**Structural Vulnerability**
SUVASTU SARINA H#1/4,BLOCK#F, LALMATIA, DHAKA-1207	ok	ok	not tested	moderate
TOTAL GODHULI PLOT-16, SECTOR-10, ROAD-11, UTTARA R/A, DHAKA	not ok	ok	not ok	high
Islampur Jame Mosque 57, 58; Islampur road	not ok	not tested	not tested	high
Jhubbu Khanam Jame Mosque, 24, Islampur road	not ok	not tested	not tested	High
Kamranga Jame Mosque Zindabahar 1st Lane	not ok	not ok	not ok	high
Mahuttuli Jame Mosque 55,Sharat Chandra Chakrobarti Road	not ok	not tested	not tested	high
Malibagh(Bangshal) Peyala Mosque, Bongshal Road	ok	not ok	not tested	moderate
Kosaituli Old Jame Mosque 26/27, K.P. Ghosh Street	ok	ok	not tested	moderate
Bangshal RokonUddin Jame Mosque, Bongshal Road	not ok	ok	not tested	moderate
Anondomoyee Girls's High School, 17-18 Kazi Muddin Siddque Street	ok	not ok	not tested	moderate
Haybotnagar Primary School 13,'Haibat Nagar Dewan	not ok	ok	not tested	moderate
Jummon Community Centre 19-1,19-2(I),'Hazi Abdur Rashid Lane	Not ok	not ok	not tested	moderate
Mokimbaza school	ok	not tested	not tested	quite good
Mahuttuli primary School 27, Sharat Chandra Chakrobarti Road	not ok	ok	not tested	moderate
Nobab Yousuf Market Mosque Nobab Eusuf Road	not ok	not ok	not ok	high
ShahjadaMia Jame Mosque 24, Shahjada Mia Lane	not ok	ok	not tested	moderate
Jindabahar Jame Mosque 54, Zindabahar 1st Lane	not ok	not ok	not ok	high
Maulana Mosque 97/98, K.P. Ghosh Street	not ok	ok	not tested	moderate
Shahjadi Begum Jame Mosque, 45, Bagdasha Lane	ok	not ok	not tested	moderate
Samsabad Boro Mosque K.P. Ghosh Street	ok	not ok	not tested	moderate
Kosaituli panchayet Committee and School 9, Kazi Muddin Siddque Street	ok	ok	not tested	moderate
Babubazar Ghat Jame Mosque Ray Eshar Chandra Ghosh	ok	ok	not tested	moderate

Building Name and Location	**Adequacy of Reinforcement**			**Structural Vulnerability**
Ahmed Bawani School and College 3/4, K.P. Ghosh Street	not ok	ok	not tested	moderate
Samsabad Primary School 79, K.P. Ghosh Street	not ok	ok	not ok	moderate
Kona Party Centre 11-12,S.C.C Road	not ok	not ok	not ok	high
Ahmedabad school 3/4, K.P. Ghosh Street	not ok	ok		moderate
Mosjid-e-Baitul-Mamur 69 French Road, Mosjid-e-Baitul-Mamur	ok	not ok	not tested	moderate
IFCDR Building, BUET	ok	ok	not ok	moderate
Eleven Storey Tower Building, BUET	not ok	ok	not ok	moderate
Civil Engineering Building BUET	not ok	ok	not ok	moderate
EME Building, BUET	not ok	ok	not ok	moderate
Library Building, BUET	not ok	ok	not tested	moderate
Architecture Building BUET	not ok	ok	not ok	moderate
URP Building, BUET	not ok	ok	not ok	moderate
ARC Building, BUET	not ok	ok	not ok	moderate
New Academic Building BUET	not ok	ok	not ok	moderate
Controller of Examination building, BUET	not ok	ok	not ok	high
Engg. University School Building, BUET	not ok	not tested	not ok	moderate
Titumir Hall, BUET	not ok	not ok	not ok	moderate
Sher-e-Bangla Hall, BUET	not ok	not ok	not ok	moderate
Dr. M.A. Rashid Hall BUET	not ok	not ok	not ok	moderate
Building Number 47, BUET	ok	not tested	ok	moderate
Building Number 62, BUET	ok	ok	ok	moderate
Fire Service Station (Head Office, Dhaka)	not ok	not ok	not ok	moderate
Ban Bhaban Main Building	ok	not tested	not ok	moderate
Ban Bhaban Extended Portion	ok	not tested	not ok	high
Fire Service Station, Lalbag	ok	not ok	not tested	moderate
Ahsan-Ullah hall, BUET	not ok	not ok	not ok	high
Shahid Smirity Hall middle Building, BUET	not ok	ok	ok	moderate
Shahid Smrity Hall north Building, BUET	not ok	ok	ok	moderate

5. SEISMIC EVALUATION FOLLOWING THE FIRST LEVEL OF SCREENING PROCEDURE

The provisions of the Standard of Japanese RC building evaluation (2001) is applied to seismic evaluation of existing reinforced concrete buildings of Dhaka. The seismic evaluation is done based on both site inspection and structural calculation to represent the seismic performance of a building in terms of seismic index of structure I_S and seismic index of non-structural elements I_N. The seismic safety of the building shall be judged based on standard for judgment on seismic safety wherein seismic performance demands are prescribed.

The standard is applied to the seismic evaluation and the verification of seismic retrofitting of existing low-rise and medium-rise reinforced concrete buildings. Three levels of screening procedures, namely the first, the second, and the third level screening procedures, are available for the seismic evaluation according to this standard. In the present study first level of screening procedure is used.

The seismic index of structure I_S can be calculated at each story and in each principal horizontal direction of a building. Here the index has been calculated for a typical story in weak direction. The seismic index of structure includes basic seismic index of structure E_O, irregularity index S_D and time index T. The basic seismic index of structure E_O evaluates the basic seismic performance of the building. It is calculated at each story and each direction based on the ultimate strength, failure mode and ductility of the building. These effects are considered by applying the strength index C, the ductility index F and the effective strength factor α. The vertical structural members are classified into three categories as column, extremely short columns and wall, according to the provision. The strength index in the first level of screening procedure is calculated approximately using the cross sectional area of walls and columns. The irregularity index S_D and time index T are used commonly for all stories and directions in the first level of screening procedure. The irregularity index S_D is to modify the basic seismic index of structure E_O by quantifying the effects of the shape complexity and the stiffness unbalance distribution, and the seismic performance of a structure with engineering judgment. The time index T evaluates the effects of the structural defects such as cracking, deflection, aging and like on the seismic performance of a structure.

Seismic index of non-structural elements I_N is to judge the safety of human lives or the security of evacuation routes against the fall-down or the spall-off of non-structural elements, especially external walls. I_N shall be calculated by following the procedures provided for the first level screening procedure for each wall in each story. In current seismic evaluation I_N is calculated for the walls based on the representative condition present in a specific story of a building. The seismic index of non-structural elements includes construction index and human risk index which shall be adopted for the external walls considering the most vulnerable construction method, that is, which gives the maximum value of the construction index, among the walls concerned. The construction index is calculated from conformability index and deterioration index. The conformability index is determined in combination of ductility grade of the primary structure and ductility grade of non-structural elements. The deterioration index is based on aging and past damages. The human risk index is based on the condition of usage below the external wall and the existence of guard such as the eaves, set back and the like.

Seismic safety of a building shall be judged by comprehensive assessment based on the seismic evaluations separately conducted on the structure and non-structural elements. Seismic safety of structure is judged by comparing the seismic index of structure and the seismic demand index of structure I_{SO}. The building may be assessed to be safe if the building possesses the seismic capacity required against the expected earthquake motions. Otherwise the building should be assessed to be uncertain in seismic safety. The seismic demand index of structure I_{SO} is calculated for first level of screening, based on the basic seismic demand index of structure E_S taken as 0.8, zone index Z as 1.2 (Rahman, 2004), ground index as 1.0 and usage index as 1.0, regardless of the story in the building. The index calculated for the seismic evaluation of a few selected buildings is enumerated in Table 3 and comment on their safety judgment is shown in Table 4.

Table 3: Seismic index of structure I_S and of non-structural elements I_N

Building	No. of Stories, n	No of Story for Evaluation, i	E_O	S_D	T	I_S	B	H	I_N
IFCDR Building	4	2	0.602	1.2	0.9	0.65	0.8	0.5	0.6
Titumir Hall	4	2	0.458	1.14	0.8	0.42	0.8	0.5	0.6
New Academic Building	12	2	1.494	1.14	1	1.70	0.8	0.5	0.6
M A Rashid Hall	5	2	0.702	1.14	0.8	0.64	0.8	0.5	0.6
Library Building	4	2	1.148	1.14	0.8	1.05	0.8	0.5	0.6
ARC Building	4	2	0.761	1.2	1	0.91	0.8	0.5	0.6
Civil Engineering Building	7	2	0.902	1.14	0.8	0.82	0.8	0.5	0.6

Table 4: Comment on safety judgment

Building	No of Stories, n	Seismic Index of Structure, I_S	Seismic Index of Non-Structural Elements, I_N	Seismic Demand Index of Structure, I_{SO}	Safety Judgment
IFCDR Building	4	0.65	0.6	0.96	Uncertain
Titumir Hall	4	0.42	0.6	0.96	Uncertain
New Academic Building	12	1.70	0.6	0.96	Safe
M A Rashid Hall	5	0.64	0.6	0.96	Uncertain
Library Building	4	1.05	0.6	0.96	Safe
ARC Building	4	0.91	0.6	0.96	Uncertain
Civil Engineering Building	7	0.82	0.6	0.96	Uncertain

6. CONCLUSIONS

In this study, the seismic vulnerability of low and medium-rise reinforced concrete buildings within six major locations of Dhaka city was investigated. The seismic evaluation has been accomplished by performing two non-destructive tests, Ferroscan and Microtremor measurements and also following the Japanese RC building seismic evaluation provision. The inspection was done by observing the structural elements and building configuration along with the resonance phenomena of the building.

Total 84 buildings have been selected for the study. Most of the buildings in BUET campus are vulnerable in consideration of resonance. Those buildings have major structural irregularities such as soft story, re-entrant corner, torsional irregularity, and mass irregularity. The poor structural quality has been identified in most of the building in Old Dhaka. These buildings have higher probability to face seismic hazard. Consequently, it could be greater threat for the people of these areas. Buildings in other areas, like Banani, Mirpur, Lalmatia and Uttara, are vulnerable due to structural irregularity as well as resonance.

On the other hand, the vulnerability assessment of the seven buildings has been performed according to the first level of screening procedure of the Japanese provision. Among these buildings, two buildings may be declared as safe on the basis of seismic safety of structural elements since they have the required seismic capacity against the expected earthquake motions. While other five buildings may be evaluated as uncertain in seismic safety and detail analysis is required to confirm this situation.

Therefore, in light of this study, it may be concluded that proper planning and better construction quality need to be ensured for future buildings of Bangladesh to survive earthquakes. For existing buildings retrofitting techniques may be applied.

REFERENCES

Aki, K. (1957). Space and time spectra of stationary stochastic waves, with special reference to microtremors, Bull. Of earthquake research institute, 35, 415-456.

Ansary, M.A., Yamazaki, F. and Katayama, T. (1996). Application of Microtremor Measurements to the estimation of site amplification characteristics, Bulletin of ERS, Vol 29, PP: 96-113.

Bangladesh National Building Code (1993). Housing and Building Research Institute, 1st ed., Dhaka.

Kanai, K. and Tanaka T. (1961). On Microtremor VIII, Bull.Earthq. Res.Inst. Tokyo University, Vol.39, pp.97-114.

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, QR of RTRI, 30, 25-33

Rahman G.F. (2004), Seismic Damage Scenario for Dhaka City, M. Sc. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology.

Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (2001).

Tamura, T., O. Nagai, H. Kikubo, and H. Sumita (1993). Charactesistics of wave group microtremors obtained by array measurement, J. Struct. Consr. Eng. AIJ 449, 83-91 (in Japanese).

Toshinawa, T., Inoue M., Yoneyama N., Hoshino Y., Mimura K., and Yokoi Y. (2003),Geologic-profile estimates of Kofu Basin, Japan, by making use of microtremor observations,Geophysical Research Abstracts, Vol. 5, 02079.

Sato, T. H. Kawase, M. Matsui, and S. Kataoka (1991). Array measurement of high frequency microtremors for underground structure estimation, proc. 4th int. conf. on seismic zonation, 11,409-416.

Development of simple system for measuring vibration by iPhone and iPad and it's evaluation by shaking table

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ABSTRACT

This research investigated the potential usage of iPhone (OS 3.1.2) and iPad (OS 3.2) for measuring vibration such as earthquake response of structure. An application was developed and which used the smart phone's built in accelerometer for collecting vibration data, and the sensor's performance was examined experimentally. The XYZ acceleration data were stored in text form and could be forwarded to an outside PC as an email attachment. The frequency response and reproducibility of seismic waves were evaluated using a small shaking table based on the pulse motor.
The developed application was installed on an iPhone and iPad, and the resolution of each acceleration sensor was compared. The frequency response of each sensor was obtained to take the spectrum ratio to the denominator of the laser displacement sensor. Though iPhone and iPad had same characteristics with the laser displacement sensor from the range of 1-10Hz, there was some influence due to noise. The reproducibility of seismic waves was evaluated for four past earthquake record. The acceleration wave could be reproduced with the acceleration sensor of Smart Phone, and the possibility of using Smart Phone to evaluate a rough seismic ground motion could be shown.
The conclusion of this research was that the iPhone and iPad can be used as the data logger of a personal acceleration sensor, which may help increase observation density during earthquakes.

Keywords: Smart Phone, iPhone, iPad, accelerograph, shaking table

1. INTRODUCTION

The strong motion observation of our country has started from the installation of the SMAC type strong motion seismograph in 1953 at Earthquake Research Institute of the University of Tokyo. The main purpose of this observation was to grasp of the seismic force acting to the structures such as the building and the civil infrastructure. As a strong motion seismograph at that time was extremely

expensive, only four places by the private cooperation and two places by national expenditures. As for the plan of nationwide development of the strong motion seismograph, the total number of the strong motion seismograph by the national expenditure increased to 16 places in 1958. Afterwards, a strong motion observation by the private company greatly exceeded the installation by the national expenditure with the high economic growth of our country, and then the total number of strong motion observation went up to about 2000 total in 1990. And, the situation of the strong motion observation intended for the ground in our country has changed greatly with the occurrence of Kobe earthquake in 1995. In 1996 Ministry of Education, Culture, Sports, Science and Technology set the seismograph network (K-NET) with 1000 seismograph of 25km interval. Moreover, KiK-net was set about 700 places in the whole country. The Meteorological Agency sets up the seismic intensity meter of 95 the Meteorological Agency types every about 600 places in the whole country, and is observing the seismic intensity.
However the strong motion observation network for the building and the individual residence, etc. is still insufficient situations to enhance the above-mentioned strong motion observation network. One of these backgrounds is that the seismograph is still expensive, and the individual cannot equip it to the house with the seismograph under the current cost. However, it pays attention to an efficient, low-cost MEMS acceleration sensor in recent years, and a basic evaluation to use it for the seismograph is conducted. Though the low-cost MEMS acceleration sensor has already been used for a domestic game machine and the car, etc, in recent year, to use it as a seismograph, the performance gain is necessary. A considerably cheap seismograph can be achieved compared with the acceleration such as the servo type sensor if low resolution of the performance of the MEMS sensor (about 1 Gal) can be allowed.
This research investigated the potential usage of smart phone for measuring vibration such as earthquake response of structure. The developed application which utilized the smart phone’s built in accelerometer for collecting vibration data, and the sensor’s performance was examined experimentally. If Smart Phone can bear a part of the strong motion observation, the formation of the observation network can be built such as the analysis of strong motion occurrence, the evaluation of the regional characteristics of earthquake response immediately.

2. DEVELOPMENT OF APPLICATION

2.1 OVERVIEW OF APPLICATION

To use the acceleration sensor built into Smart Phone, the application that preserves acceleration data, display it as waveform and transmit it to the outside PC was developed with Mac mini equipped with Intel CPU. Mac OS X snow leopard 10.6.4 was used as OS, and Xcode 3.2.3 and iPhone SDK 4 were used as a development setting.
The acceleration data in real time shape of waves displayed three components (X, Y, and Z) on the screen of Smart Phone as time history. The collection of data began with "Record" button, and stopped with "Stop" button, and then outputs acceleration value (G) of three elements of the data acquisition time and XYZ to

the file by the text form. The XYZ acceleration data was stored in text form and could be forwarded to an outside PC as an email attachement, and a detailed analysis on PC becomes possible (Figure 1).

2.2 RESOLUTION

The developed application was installed in iPad (OS 3.2) and iPhone (OS 3.1.2), and the resolution of each acceleration sensor was compared. The result of acquiring the maximum value, minimum value, and resolution of each axis X, Y, and Z axially from the measurement data are shown in Table 1.
As for iPad, the range of the resolution of each axis is roughly 0.001G because it becomes from 0.000992 to 0.001007 with unsteady of each XYZ axis.
The number of the AD converter bit of iPad and iPhone can be evaluated as 8 bit and 12 bit. The sampling frequency was both 100Hz.

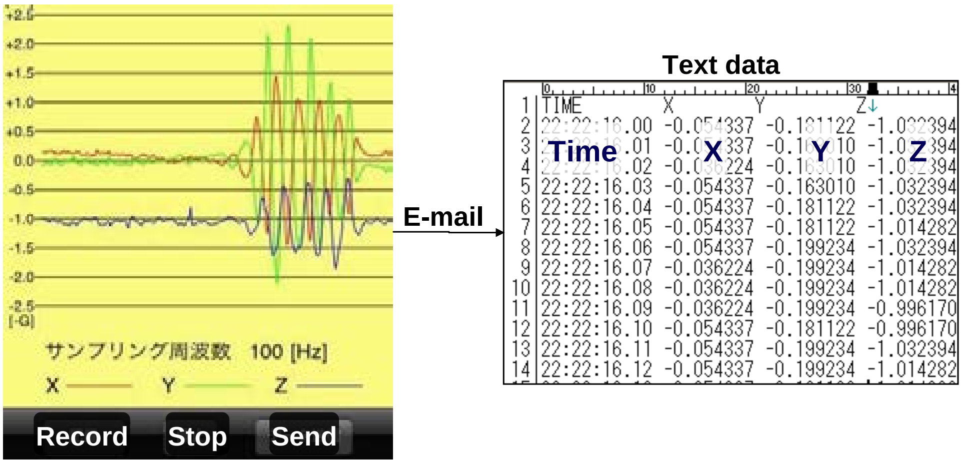

Figure 1: Smart Phone application

Table 1: Property of iPhone and iPad

		X	Y	Z
iPhone 3.1.2	Min [G]	-2.300247	-2.300247	-2.300247
	Max [G]	2.318359	2.318359	2.318359
	Resolution [G]	0.018112	0.018112	0.018112
	Bit	8	8	8
	Sampling frequency [Hz]	100	100	100
iPad 3.2	Min [G]	-2.039993	-2.046997	-2.047989
	Max [G]	2.046997	2.039993	2.038986
	Resolution [G]	0.000992	0.000992	0.000992
	Bit	12	12	12
	Sampling frequency [Hz]	100	100	100

3. SHAKING TABLE TEST

3.1 OVERVIEW OF SHAKING TABLE TEST

The vibration property of the acceleration with built-in Smart Phone sensor was examined by using a small shaking table based on the pulse motor (Figure 2).

This small shaking table is an evaluation system for a simple vibration sensor by the pulse motor drive. The fixed table on the sliding base is driven by timing belt controlled by the high-speed switching of the pulse motor of CW (Clock Wise) and CCW (Counter Clock Wise) rotation. A peculiar pulse noise to the pulse motor even in the low-frequency area is unremarkable because the gear system is not used, and high resolution was achieved with the micro-step mechanism. This shaking table has been developed to measure the frequency response of the velocity and the acceleration sensor for the main purpose, and it can drive especially by controlling the pulse motor with the micro-step mechanism in the low frequency until about 100 cycles per seconds. On the other hand, in the range of high-frequency, maximum frequency range from 15Hz to 20Hz due to the low-speed element such as the restrict of an internal torque of the motor and data transfer speed of USB controller. Because the frequency response characteristics of the speed and the acceleration sensor is normally constant (linearity) for the size of the amplitude within the wide range of the frequency in many cases, the comparative large amplitude can be evaluated.

Smart Phone used for the shake table experiment is two models of iPhone(OS 3.1.2) and iPad(OS 3.2), and the accelerometer (JA40GA, 2V/G output, 1mgal resolution) and the laser displacement sensor (5mm/V output) are used for the comparison of Smart Phone characteristics as same time. The two differential of the displacement obtained by the laser displacement sensor is used as a standard of the acceleration. The shaking pattern is a linear sweep wave with half amplitude of 0.5mm and the frequency from 0.1 to 20Hz. And then, the four observation seismic waves (Mexico earthquake, 1985, Hyogoken-nanbu earthquake, 1995, Tokachioki earthquake, 2003 and Niigata-chuetsu earthquake, 2004) are applied.

(a) Sensor on the shaking tabel

(b) PC controlling shaking table

Figure 2: Photo of shaking table test

3.2 Result of shaking table test

3.2.1 Sweep test

Figure 3 shows the vibration response of iPhone, iPad, the laser displacement sensor and JA40GA by the linear sweep wave from 0.1 to 20Hz. The measurement was conducted twice. The first measurement case, it was upper one and second case it was bottom one. A big difference was seen in the amplitude of each sensor, and the difference of the response lead-time was not seen. The time to obtain the maximum value of the amplitude was the almost same.

The frequency response of each sensor was obtained to take the spectrum ratio to the denominator of the laser displacement sensor (Figure 4). Though iPhone and iPad had same characteristics with the laser displacement sensor from the range of 1-10Hz, there was some influence due to noise.

On the other hand, JA40GA as for the comparison to iPhone and iPad shows the high accuracy to the laser displacement sensor in the range of 1 to 10Hz.

Figure 5 shows the resolution of the acceleration sensor of iPhone and iPad read from the silence part. The resolution of the sensor with built-in iPhone and iPad are about 18 Gal and 1 Gal respectively.

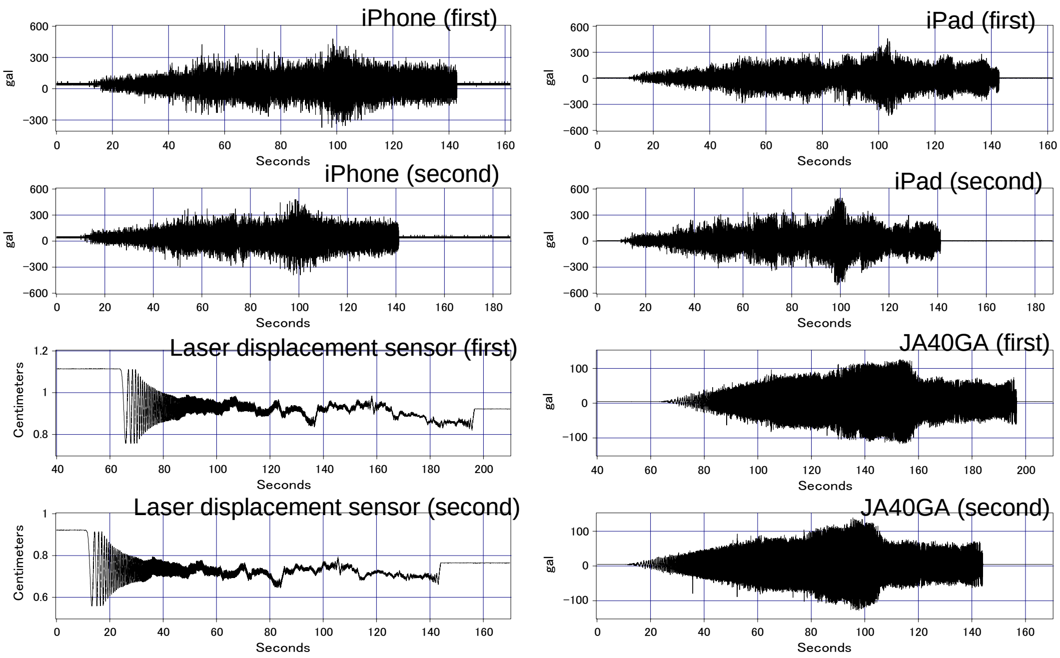

Figure 3: Response of sweep test

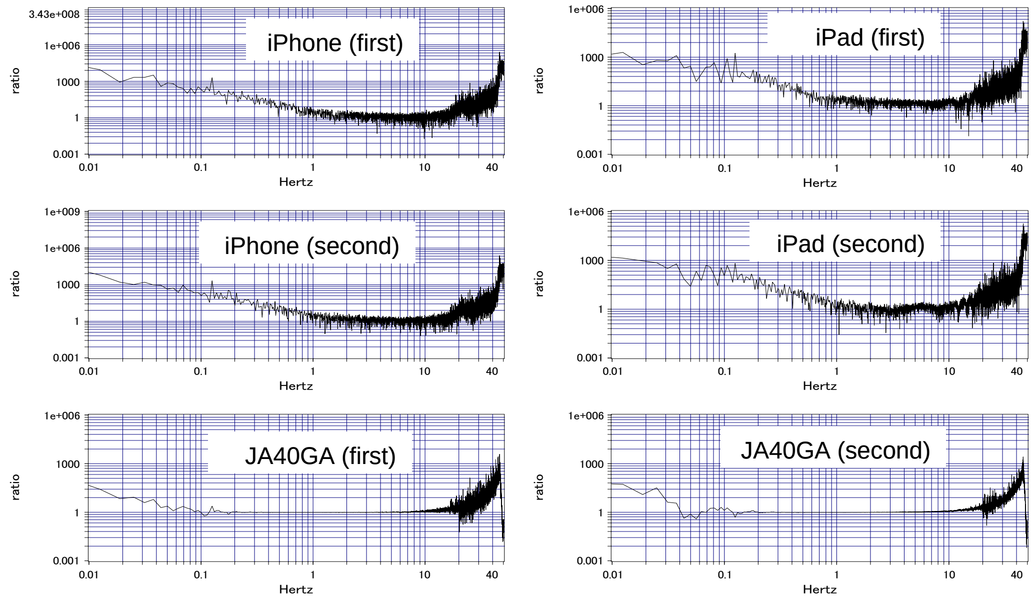

Figure 4: Spectrum ratio to the denominator of the laser displacement sensor)

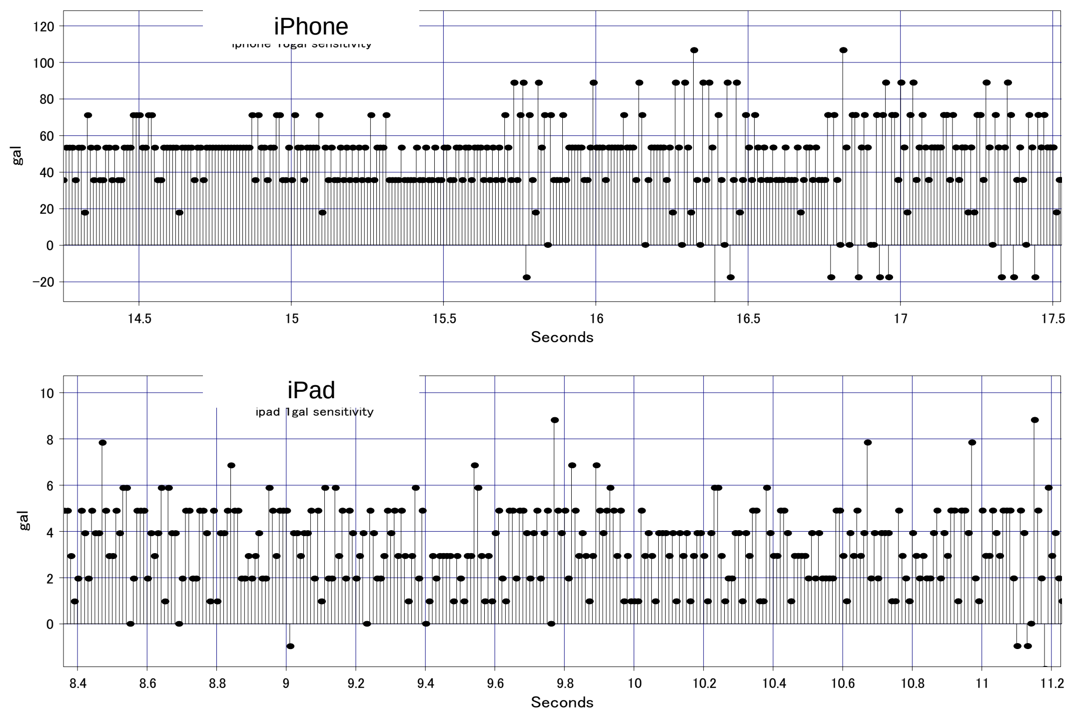

Figure 5: Resolution of iPhone and iPad

3.2.2 Seismic wave test

Figure 6 shows the input data of seismic wave for the shaking table test. These input data are used to drive the pulse motor as a velocity that the acceleration earthquake records are integrated.

The response of each sensor to the input seismic wave is shown in Figure 7. Same measurements are conducted twice. The upper part shows the first measurement result and the result of second time is shown in the lower part.
As the large amplitude was obtained in the Mexico case and Tokachi-oki earthquake case due to the noise partially, however the appearance of seismic wave was reproduced.
Figure 8 shows the fourier spectrum of each sensor in the case of Niigata-chuetsu earthquake.
As the shape of the fourier spectrum in iPad case is similar to the case of JA40GA, the response of iPad with better re-productivity to JA40GA, perform better than that of iPhone. The performance of iPad has improved compared with iPhone.
Therefore, iPhone and iPad are available to evaluate the seismic wave roughly, because the past seismic wave motion can be re-produced by these sensor by the small shaking table test as long as fixation is steady.
There are some problems of Smart Phone such as the limitation of the operating time depending on the OS etc. However, these tools are worth to examine the possibility to collect the seismic data from the following advantages; the cheapness, easy operating and widely distributed in out society.

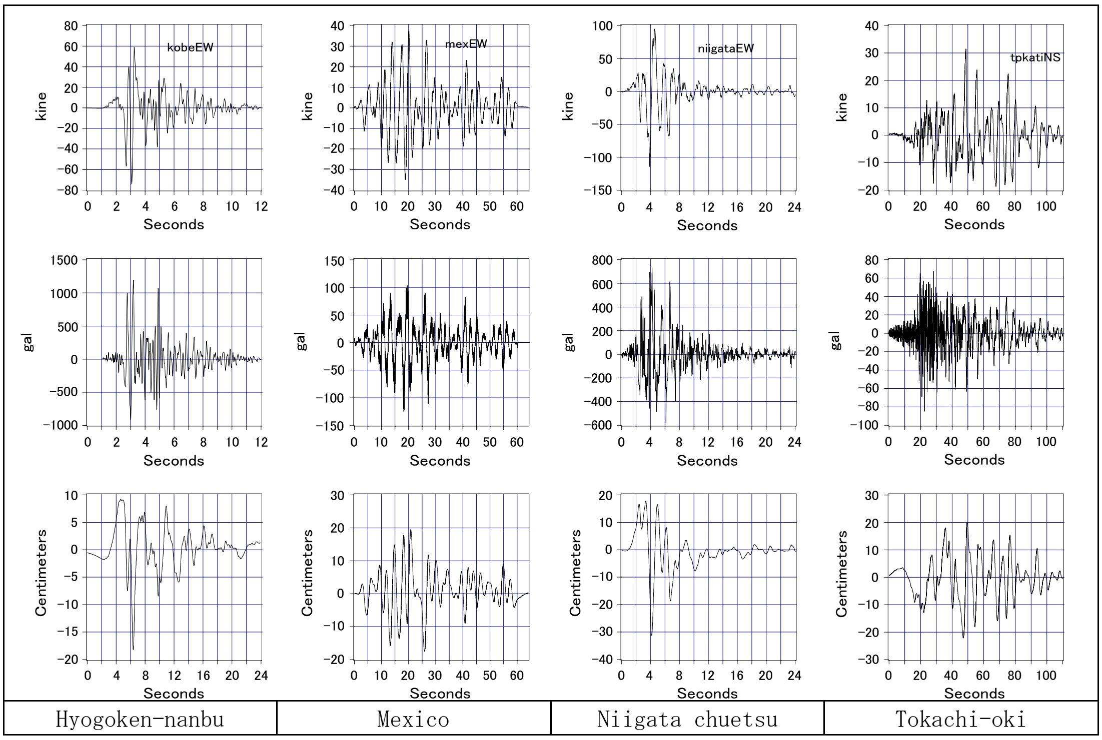

Figure 6: Input seismic wave to shaking table test

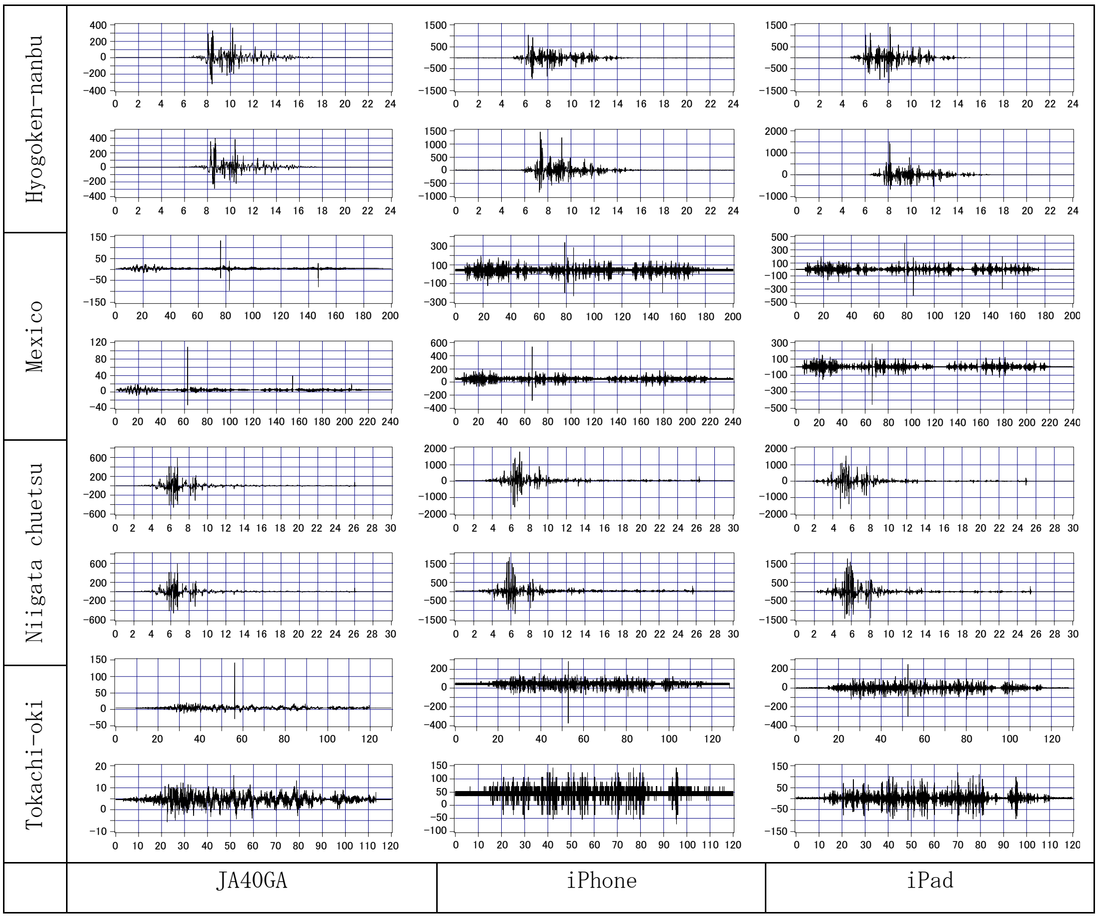

Figure 7: Response of shaking table test (vertical axis: Gal, Horizontal axis: time, upper side: first test, bottom side: second test)

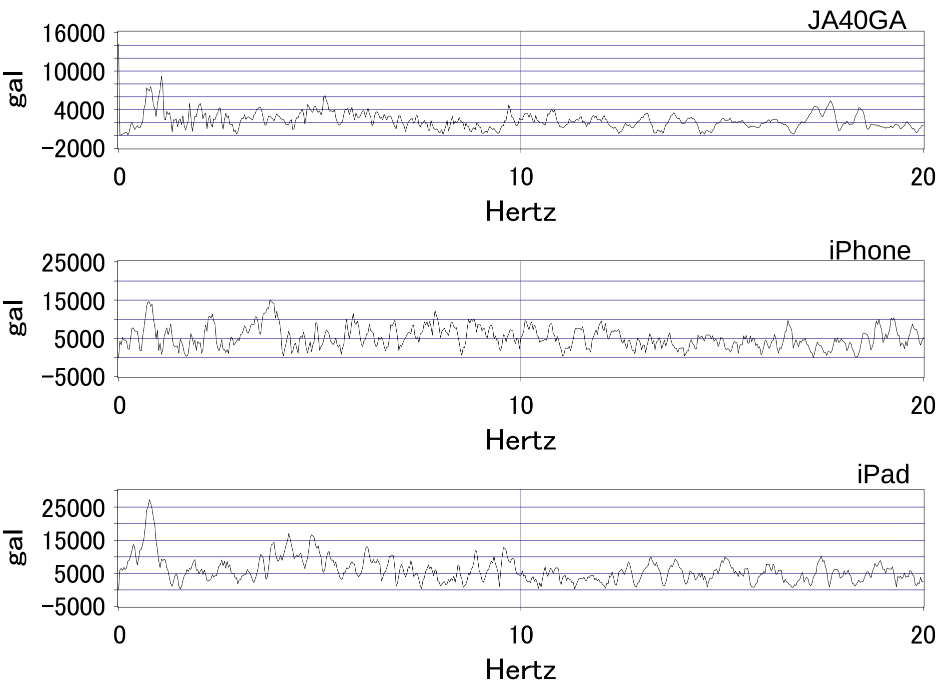

Figure 8: Fourie spectrum in the case of Niigata- chuetsu earthquake

4. CONCLUSION

This research investigated the potential usage of iPhone (OS 3.1.2) and iPad (OS 3.2) for measuring vibration such as an earthquake response of structure. The developed application, which utilized the smart phone's built in accelerometer for collecting vibration data, and the sensor's performance was examined experimentally.

The conclusion of this research was that the iPhone and iPad can be used as the data logger of a personal acceleration sensor, which may help increase observation density during earthquakes.

Current Smart Phone cannot utilize the seismograph of high/enough accurate, however it is possible to apply it as a data logger of a personal acceleration sensor as a tool that reinforced a high density system of the current observation network.

The applicability to disaster prevention measure system and the education will be examined by using the characteristics of Smart Phone which are the telecommunication facility, easy user interface and the great number of users.

REFERENCES

Fukuwa, N., Koide, E., and Itoigawa, K. 2003. Development of low-coast seismograph, *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, Architectural Institute of Japan*, 871-812.

Kurata, N., Saruwatari S., Horie S., Morikawa H., and Aoyama T., 2006. Development of Acceleration Sensor Module for Ubiquitous Sensor Networks, *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, Architectural Institute of Japan*, 419-420.

Nakamura, M., Yanase, T., Ikegaya, S., En, K., and Yoneyama, K., 2008. Development of smart vibration sensor for the structural health monitoring (Structures), *AIJ Journal of technology and design* 14(27), 153-158.

Strong motion observation subcommittee of Architectural Institute of Japan, 2003. The future concerning strong motion observation in building (discussion), *Strong motion observation subcommittee report*.

Geotechnical Database for the 2007 Niigataken Chuetsu-Oki EQ Study

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ABSTRACT

The 2007 Niigataken Chuetsu-Oki Earthquake at the central north coast of Japan has resulted in a large variety of geotechnical damages in the Kashiwazaki City and surroundings, such as very strong ground shaking at the downtown of Kashiwazaki City and ground deformations at the Kariwa Nuclear Plant site.
This paper presents a GIS geotechnical information system that is developed for the study of the 2007 Niigataken Chuetsu-Oki Earthquake. This is a web based geotechnical information system that uses the same platform of web based "Kobe JIBANKUN". To identify the dynamic properties of ground, not only the borehole data but also other dynamic measurement data such as SASW data gathered in and around the Kashiwazaki City were also included in the system. Through the use of this geotechnical database, a study was made on the dynamic response of the downtown, particularly to identify the geotechnical and seismic profiles of the ground in and around the Kashiwazaki City. Also detailed stratigraphic and seismic profiles beneath the downtown were identified by using the GIS geotechnical database.

Keywords: *earthquake, geotechnical database, GIS*

1. INTRODUCTION

The M6.8 Niigataken Chuetsu-Oki Earthquake occurred in July 16th, 10:13 am, and large aftershock soon followed 3:37 pm. The mainshock had an estimated focal depth of 17 km and the epicentre is located in the Japan Sea offshore of the Kariwa village, at N-37degree 33.4', E-138degree 36.5' (JMA, 2007), 20 km north of the Kashiwazaki City as shown in Fig. 1. A large nuclear plant, the Kariwa Nuclear Plant of the Tokyo Electric Company (TEPCO), is located closer to the epicentre, and this was first time that a nuclear plant has been hit by a large earthquake with significant operational damages. The Kashiwazaki City was hit most severely and 14 of residents were killed with the housing damages of over 1100 collapses. The Kariwa village near the nuclear plant was also severely

Figure 1: Epicenters of the 2007 Earthquake, and other earthquakes in Niigata

affected with one death toll and over 150 houses collapsed. The downtown of the Kashiwazaki City is located on the sand dune and there were measureable ground deformation in the downtown that resulted in many housing damages. Also there have been many liquefaction damages in and around the City as two rivers, the Sabaishi River and the U River, run north and south sides of the City respectively by forming a river delta along them.

It is also to be noted that there have been several strong earthquakes over the past 50 years in nearby areas of the Niigata Prefecture. The most recent earthquake was the M6.8 Niigataken Chuetsu Earthquake of 2004 of which epicentre is located about 25 km east of Kashiwazaki. Also the 1964 Niigata earthquake has given a huge liquefaction damage to the Niigata City which is located about 75 km north-east of Kashiwazaki. The locations of these earthquakes are also shown in Fig. 1. The Kashiwazaki City suffered some damages from both of these past earthquakes. Thus it is very important for this area to have a good earthquake preparedness to minimize the damages and losses from the future earthquake disasters. Because the ground condition in Kashiwazaki and around is rather poor with respect to the earthquake shaking, it would be vital for the area to have a good knowledge base for a seismic study, such as of constructing a detailed seismic and geotechnical information database by using GIS system to disseminate and share the information among those concerned.

In the summer and fall of 2008, field investigation of SASW tests were conducted by the authors to further identify the dynamic properties of ground. A visit to the Kashiwazaki City civil engineering office was made subsequent to the field tests, and a large number of borehole investigation data were given to the authors from which a geotechnical database as discussed in this paper was constructed. The objectives of this study is to summarize the findings made through the above field testing and the construction of geotechnical database to further enrich the earthquake risk assessment study to minimize the future seismic risks.

2. OUTLINE OF GEOTECHNICAL DAMAGES AT THE DOWNTOWN AND AT AROUND THE KASHIWAZAKI CITY

This earthquake has resulted in an abundance of ground damages around the Kashiwazaki City and also at the downtown. The downtown area of Kashiwazaki City is built on the sand dune that had a height of 10 m approximately above the horizon. The downtown area of the Kashiwazaki City was heavily damaged due to noticeable ground movements from the higher ground to the lower parts of the sand dune.

Fig. 2 is a map of cracks that appeared on pavements in the downtown area. Red

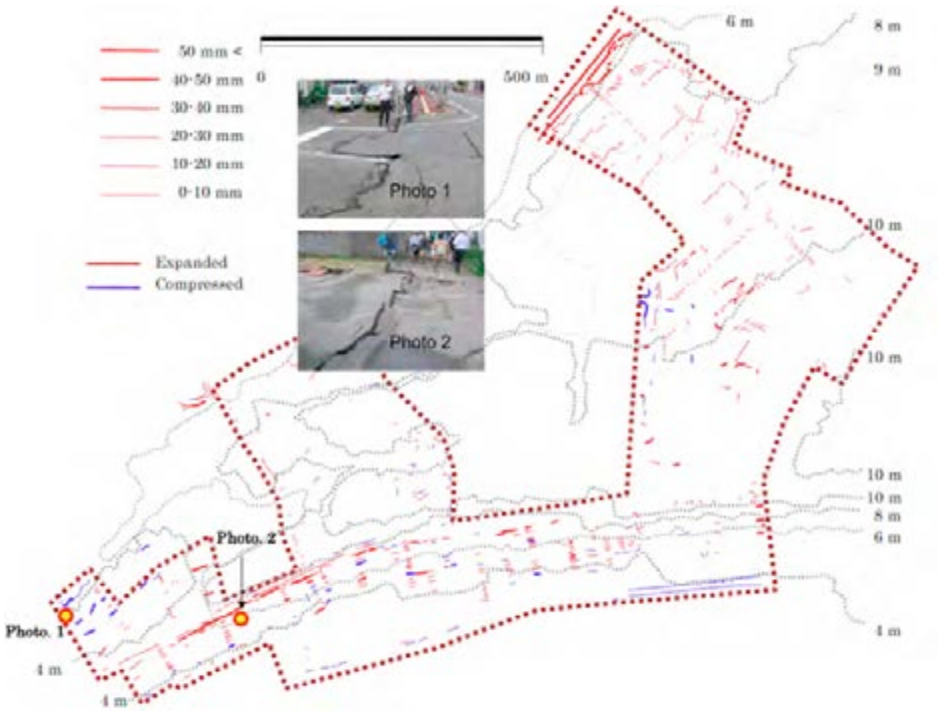

Figure 2: Pavement Cracks of the Kashiwazaki City Downtown

and blue lines show respectively open cracks (photo 1) and compressed marks (including those colliding over the others, buckled up; see photo 2). Most clusters of open cracks are found along ridges of the sand dunes while many compressed marks were found along toes of the dunes and some were found along an S-shaped sagged zone among the sand dunes. These cracks and compressed marks show that the steep slopes of these sand dunes have subsided towards wet flatlands and sagged zones.

A housing damage study in Kashiwazaki downtown was carried out by Higuchi et al. (2007) of Nagaoka Institute of Technology, and they also have shown that most of housing damages are located where the ground movements are in expansions mode and these are located along the top edges of sand dune.

Northern part of Kashiwazaki, the Nishiyama and Arahama areas, is also hit by the earthquake. In these areas, there is a thick deposit of soft clays being deposited against a steep hill of sand dune and uplifted basal rock at the west. The Arahama railway station and a DIY store, “Plant5”, were heavily damaged by strong motion.

3. THE KASIWAZAKI GEO-HAZARD STUDY MAP

As noted earlier, the Kashiwazaki City civil engineering office has provided the authors the borehole data available in and around the City, Hajime Tanaka (2008). Also we have conducted SASW tests at fourteen sites. In order to study the seismic response and the cause of ground damage at Kashiwazaki, it was thought best to create a geotechnical database using a GIS system that can be used easily to locate and examine the geotechnical data at the damage site. A similar work of creating a geotechnical GIS database has been in progress to examine the geo-hazards of the 1995 Kobe Earthquake (http://gdc.cee.tufts.edu/) through a collaborative study between the Tufts University of USA and the Kobe University of Japan. It was thus decided to create a geotechnical GIS to study the geo-hazards during the 2007 Niigataken Chuetsu-Oki Earthquake by using the same GIS software to integrate the given borehole data and the SASW tests. Fig. 3 shows an example page of such GIS database system developed to illustrate the locations of fourteen SASW test sites and also the borehole data at in and around the Kashiwazaki City. The borehole log and the SASW test results can be easily examined by clicking the borehole or SASW site name as listed in the data list box in the right side of the figure. In the followings, the geotechnical conditions at the Kashiwazaki downtown and the lowland east of the Kariwa Nuclear Plant is examined by using these SASW test results and borehole data to demonstrate the

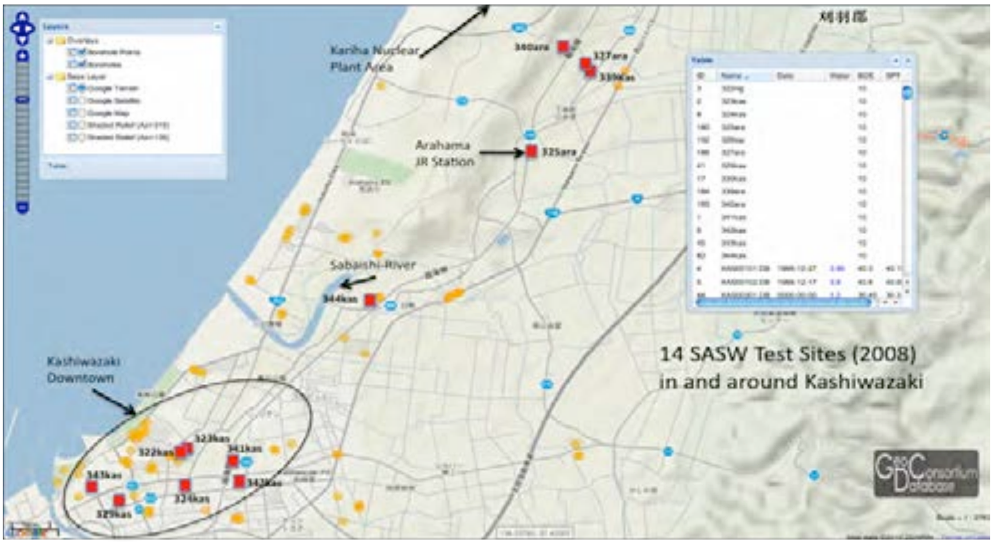

Figure 3: Locations of SASW test sites and available borehole data (i.e., orange circles) at Kashiwazaki

advantage of using such GIS geotechnical database for seismic hazard study.

3.1 NIED Seismic Monitoring Station at Kashiwazaki Downtown

As noted earlier, the downtown of the Kashiwazaki City was hit most severely, and 14 of residents were killed with the housing damages of over 1100 collapses. The major reason for this damage is thought to be the soft ground condition of Kashiwazaki downtown as it is located on a sand dune deposit, about 10 meter

high, overlying a thick soft delta deposit. The seismic amplification on such ground condition would be very severe. The seismic record at the downtown is obtained at one of seismic monitoring stations of the K-NET (Kyoshin-Net), which is a strong ground motion monitoring system run by National Research Institute for Earth Science and Disaster Prevention (NIED) to cover seismic activities all over the Japan.
Fig. 4 shows the seismic record at the K-NET station, NIGO18, that was located at the downtown city office. The maximum acceleration as computed from all three components was nearly 800 gals (JMA 2007). It is also significant that the seismic waves after about 24 seconds have a spike shape response indicating possible occurrence of liquefaction due to cyclic mobility.

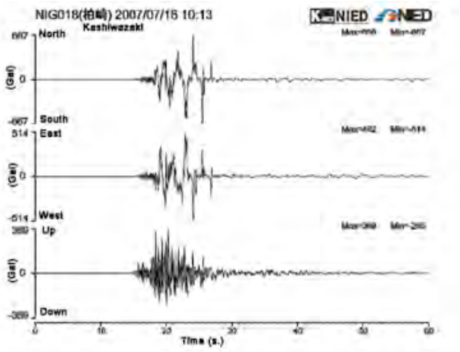

Figure 4: Seismic records as measured at K-NET.NIGO18, station

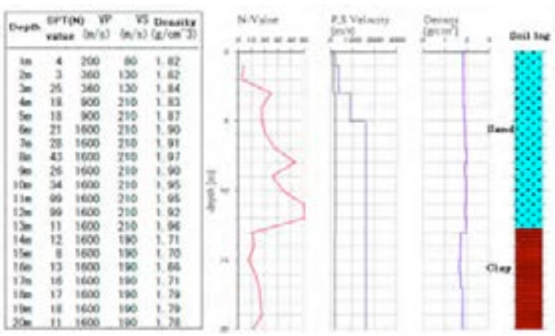

Figure 5: Geotechnical profile at K-Net

The SASW test was performed at this site to examine the seismic profile of ground. Also at the K-NET NIGO18 station, a velocity logging data during its installation is available so that a comparison with the SASW test result is possible. Fig. 5 shows the geotechnical profile as obtained from the K-NET site investigation, and the exploration depth only covers 20m. The velocity data of Fig. 5 is obtained using either downhole test or suspension type test. As can be seen from Fig. 5, a 13 m thick sand layer overlies the clay layer below. Both the SPT values and the shear wave velocity, Vs, value show that the underlying clay is softer than the sand layer above. The seismic ground profile as obtained from the SASW test was much deeper than that shown in Fig. 5 and thus the GIS geotechnical data base is used to compare the SASW seismic profile to those borehole data with deeper soil profile as shown in Fig. 6. The comparison of Vs profile between the PS logging of K-NET and that from the SASW test is in good agreement although the Vs value for the underlying clay is lower for the SASW test. The Vs value of underlying clay increases from the depth of 22 m approximately, while the SPT values as given in the borehole testing data do not show a sharp increase as the Vs value of the SASW test indicates.
In the Kashiwazaki area, the thick deposit of underlying clay is consisted of several soil strata with two different geological background. The upper clay stratum being the most recent Holocene deposit, while the lowest clay being the Pleistocene deposit. The agreement in the thickness of lower Vs layer and that of the uppermost soft Holocene clay layer is clear from the figure, and the Vs value seems to increase at lower deposit with depth. The existence of lower Vs layer beneath the sand deposit was also found at other SASW test sites in the downtown. Fig. 7 shows a continuous zone of low Vs stratum that would indicate the

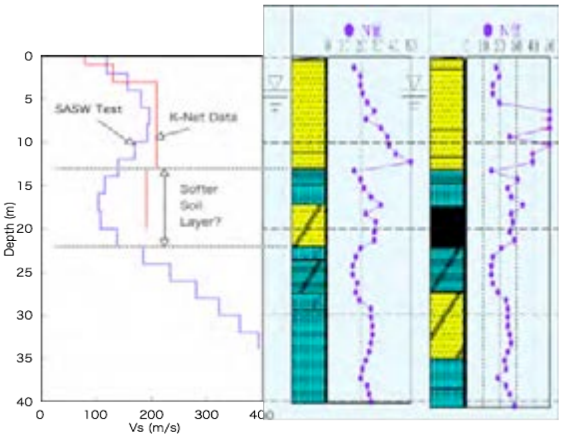

Figure 6: Comparison of the SASW seismic profile with nearby deeper boreholes

Figure 7: A low Vs layer beneath sand layer

existence of soft clay layer. The above SASW test result is useful in analyzing the seismic record at the K-NET station, but the engineering seismic base for the area is not yet to be defined.

3.2 Lowland East of the Kariwa Nuclear Plant

At the north of the Kashiwazaki City, extensive liquefaction sites were observed along the Sabaishi River. Also there have been various geotechnical damages along the west end of the lowland, north of the Sabaishi River, where the soft Holocene materials are deposited against the dipping slope of a mass of sand dune and sedimentary rock that forms the highland of the Kariwa Nuclear Plant. The typical damages found are the JR Arahama station where sharp bends of railway track, the collapse of the Arahama Station's platform, and a large lateral movement of foundation at PLANT 5, DIY store that resulted in a buckling of concrete floor slab as reported by Kayen et al. (2007).

At this site, five SASW testing have been carried out to investigate the dynamic properties of ground and these locations are shown in Fig. 8. Also shown in the figure are the borehole logs nearby the SASW test sites. The ground at the lowland consists of very soft clay showing very low N values, and the thickness of soft clay reaches nearly 40 meters. In both the JR Arahama and the PLANT 5, there were evidence of liquefaction, but these boreholes indicate mostly clayey

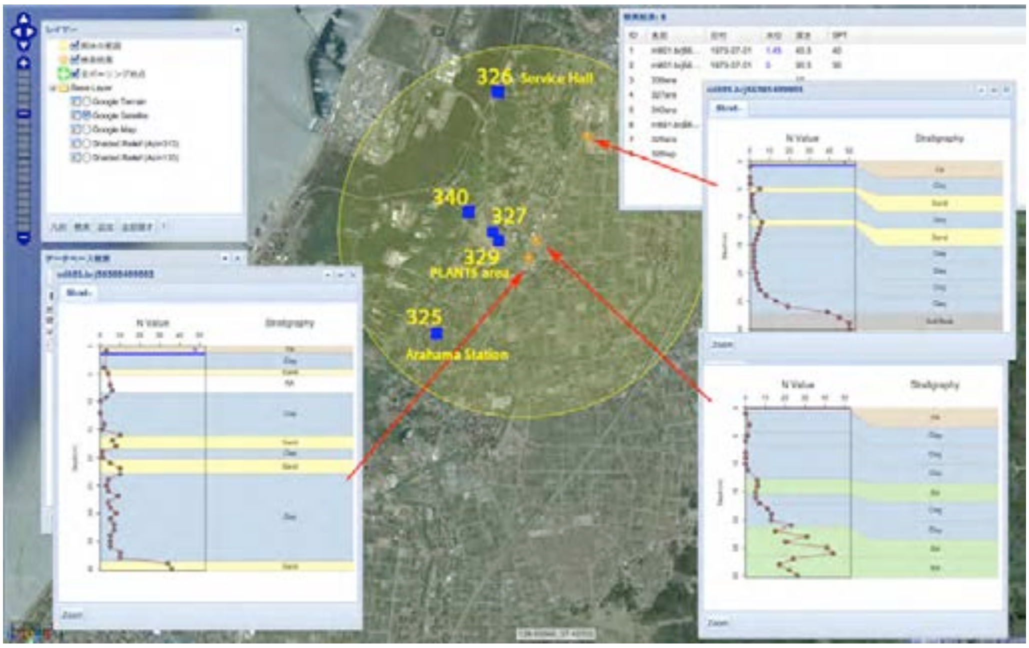

Figure 8: Locations of SASW testing and nearby boreholes

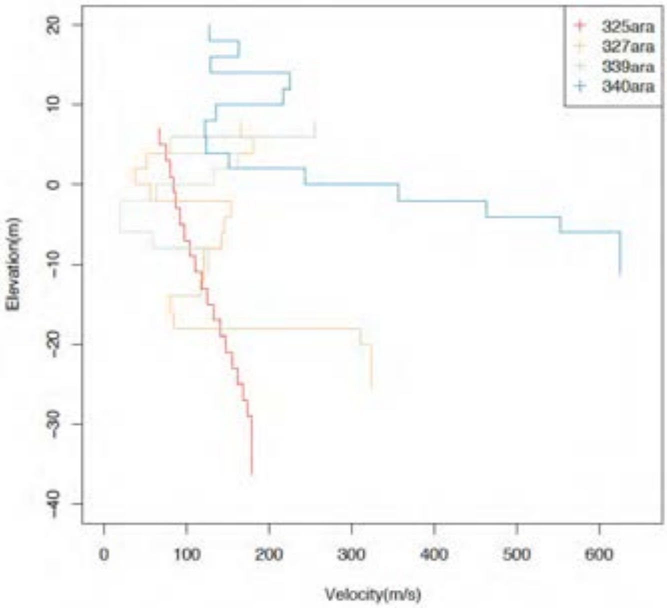

Figure 9: Depth profile of Vs from SASW testing.

deposits except for a very thin layer of sand at 5 meter below. The cause of large ground movements at these sites needs to be studied further. Fig. 9 shows the depth profile of Vs at the lowland area, and the Vs value for the soft clay ranges from 50 to 150 m/sec. Also the Vs value is larger at the depth deeper than about 20 m from the surface, but such increase of Vs value is not clearly found from the N-value profile of the boreholes. It may be noted the 340 SASW site is located on the sloping ground to the lowland, and the increase of Vs value at 20 m may indicate the presence of sand dune and sedimentary rock at the depth.
Along the perimeter road of the Kariwa Nuclear Plant, there is a vertical array seismometer is installed at Service Hall as noted earlier. A SASW test was also

conducted at this site. Fig. 10 presents a comparison between the Vs profiles from the SASW and that obtained by TEPCO during the seismometer installation. Although the Vs profile of SASW test varies depending on the assumed water level, these Vs profiles are very similar except for lower Vs values near the ground surface. A dynamic response analysis based on a more detailed Vs profile is needed to study the effect of detail Vs variation with depth on the seismic response of the ground.

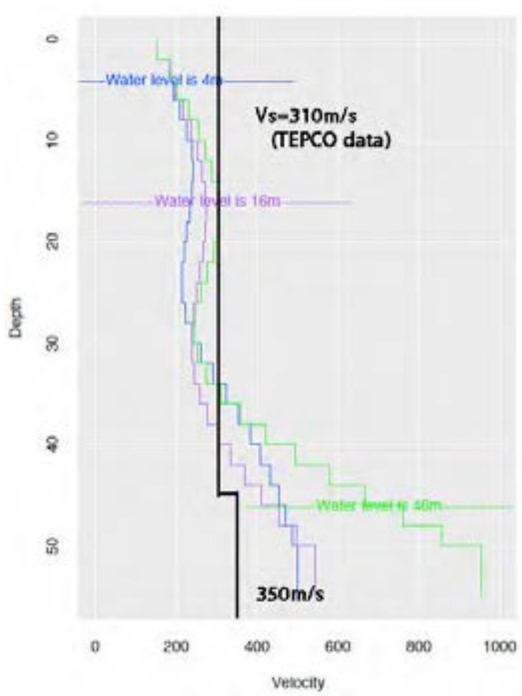

Figure 10: Depth profile of Vs at Service Hall near the Kariwa Plant.

4. CONCLUSIONS

A GIS geotechnical information system is developed for the study of the 2007 Niigataken Chuetsu-Oki Earthquake based on the borehole data given from the Kashiwazaki City. The dynamic properties of ground based on the SASW test and borehole data gathered in and around the Kashiwazaki City were also included in the system. Through the use of this geotechnical database, the dynamic properties of the grounds at the downtown and the north of the Kashiwazaki City, and also stratigraphic and seismic profiles were identified by using the GIS geotechnical database. These data would be useful for carrying out further dynamic response studies.

REFERENCES

Committee on Geology Map of Niigataken (2000): “Geology map of Niigataken and report”, Chamber of Commerce and Promotion, Niigata prefecture (in Japanese)

JMA 2007: “A quick report on disaster and tsunami - 2007 Niigataken Chuetsu-Oki Earthquake”, JMA Report on natural phenomenon during disaster, No.3, 2007 (in Japanese).

Kayen, Robert, et. al. (2007) : “Investigation of the M6.6 Niigata Chuetsu Oki, Japan, Earthquake of July 16, 2007”, Open FIle Report 2007-1365, U.S. Department of the Interior, U.S. Geological Survey

Tanaka, Hajime (2009) : “Spectral Analysis of Surface Wave (SASW) at Kashiwazaki City and its vicinity severely hit by the Niigataken Chuetsu Oki earthquake,and interpretation of its result”, Master Thesis, Dept. of Civil Eng., Univ. of Tokyo

Tomiyasu, Y., Nomura, F., Konagai, K. (2008): Pavement damages at Kashiwazaki City during the Niigataken Chuetsuoki EQ., annual meeting of JSCE, I-258, p. 515~p. 516 (in Japanese)

Retrofitting by High Sophisticated Bonded Anchorage Systems

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ABSTRACT

Anchorages afford an economic way to connect retrofitting systems with existing concrete structures. Especially bonded anchorage systems are applied frequently in the last years because of its flexible use. The connection between the existing building and the rebar, which is easy accessible on the site, is made by a drilled hole and adhesive. New technology of adhesive has developed bond strengths in excess of 30 MPa combined with stable long term behavior under sustained loads. This offers a new application range for strong connections between existing structures and retrofitting systems. State-of-the-art fastening solutions such as rigid connections between steel or concrete and existing structures are highlighted and their advantage is discussed in this paper. Based on that, finally codes and approvals are focused and the opportunity of their adaption is discussed.

Keywords: *retrofitting, adhesive, fastenings, anchorage, Japanese guideline, European guideline, ETAG*

1. INTRODUCTION

Post installed anchorage in concrete is applied frequently because of its flexible use in all kinds of connections in concrete structures. It finds widespread application for the fastening of nonstructural elements to structures and is frequently used to connect new structural elements to existing structures in earthquake retrofit schemes. Although the majority of fasteners on the market today are designed and tested for use in non-seismic environments, they are commonly used for applications in structures located in earthquake regions. Inadequately tested or inappropriately used fasteners can lead to unanticipated behavior that can compromise structural performance during an earthquake and endanger human life. Recently the field of maintenance and retrofitting of concrete buildings has grown, therefore post installed adhesives are used more often, and also their requirement of long term behavior has been increased (Mihala et al., 2009).

Both the fastening industry and practicing engineers have recognized the advantages of standardized qualification of fasteners for specific applications. Qualification is the process by which products are tested using standardized methods and granted an approval based on prescribed acceptance criteria (Hoehler, 2006). In Europe these approvals are regulated by the relevant European Technical Approval (ETA).

1.1. Applications for fasteners in earthquake regions

Basically anchorage can be used for nonstructural or structural usage (Figure 1). In the case of retrofitting the application is typically structural, increasing the demand on long term behavior and safety. The global behavior of the structure is influenced by the retrofitting structure and in the case of large earthquakes it is basically used for a seldom event.

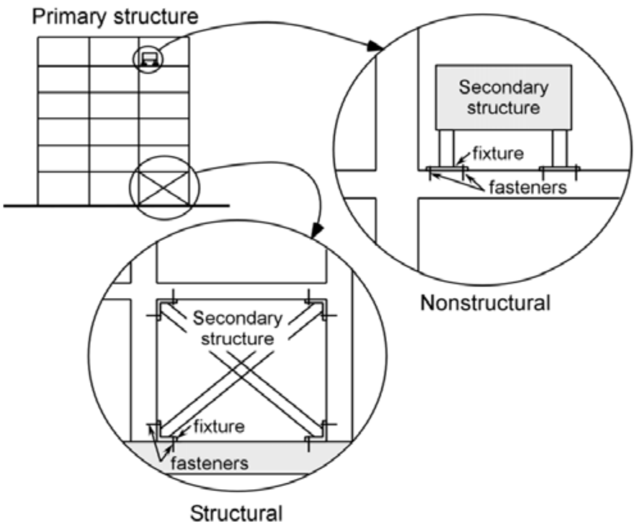

Figure 1: Structural and nonstructural applications for fastenings (Hoehler, 2006)

One common way of strengthening an existing concrete building is to increase the shear capacity. This can be accomplished by shear walls or steel braces shown in Figure 2, and the connection of the secondary structure is frequently made by bonded anchors. The difficulty of drilling the holes into the existing concrete depends on the level of reinforcement and on the required borehole depth. In some cases the borehole depth is limited by the thickness of the existing concrete member. Hence efficient ways of load transfer by high sophisticated adhesives facilitate the application.

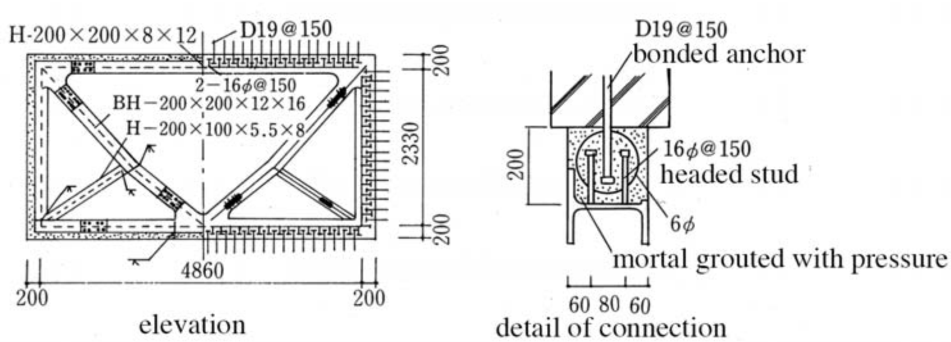

Figure 2: Example of the use of post installed anchorage for retrofitting, steel brace, (Guidelines for Seismic Retrofit, 2001)

Most of those secondary structures are applied for the rare case of large earthquakes. The deformation of such a structure (steel brace or shear wall) is shown in Figure 3. Experiments (Comitée Euro-International du Béton, 1995) have shown that the best result occurs if the shear wall is connected uniformly with the existing structure. First of all the deformed structure shows a diagonal compression strut which is introduced into the existing structure. The other diagonal under tension produces gaps which have to be minimized through the use of anchorage as connectors. In addition to the shear transfer the transfer of tension forces plays a serious impact on the global behavior.

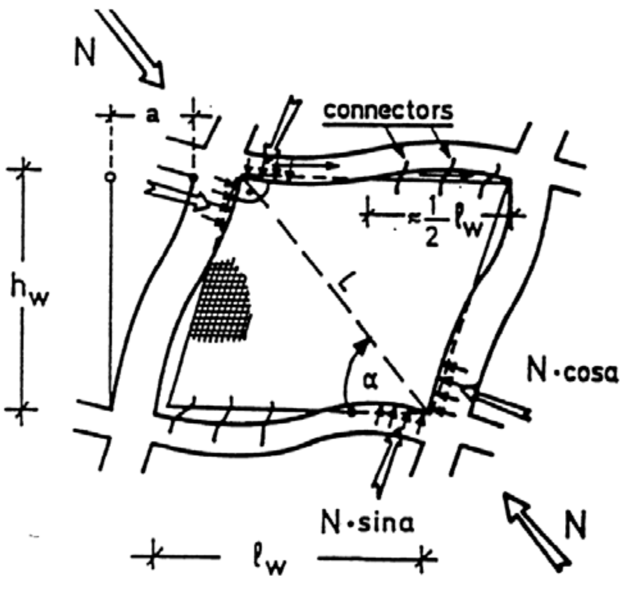

Figure 3: Deformed post installed shear wall at earthquake loading (Guidelines for Seismic Retrofit, 2001)

Mainly these connectors are located close to the edge, and without proper guidelines it is a difficult situation for the design engineers to estimate the proper way of installation. The current Japanese guideline is compared with the corresponding European standards and the case of tension load is focused in the following.

2. POST INSTALLED ANCHORS UNDER AXIAL LOAD

The development of efficient drilling methods made it possible to install post installed anchors in a fast and safe way. Especially bonded anchors are used close to edge because of their flexible use and lower splitting force compared to expansion anchors or even cast in place rebars (Figure 4).

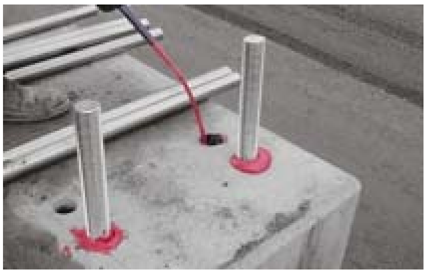

Figure 4: Application of bonded post installed anchorage

2.1. Tensile capacity of bonded anchors and failure modes

The basic failure modes without edge influence are shown in Figure 5. If the embedment depth is large, and the diameter of the anchor is small, the decisive failure mode of post installed bonded anchors in concrete occurs in the anchor itself (Figure 5 a). Due to the well known material behavior of steel, this failure mode has a low mean variation and a sufficient ductility which is desirable in the case of earthquakes. Concrete cone failure (Figure 5 b) depends on the embedment depth and concrete strength, and pull out failure (Figure 5 c) depends on both, the embedment depth and the used adhesive.

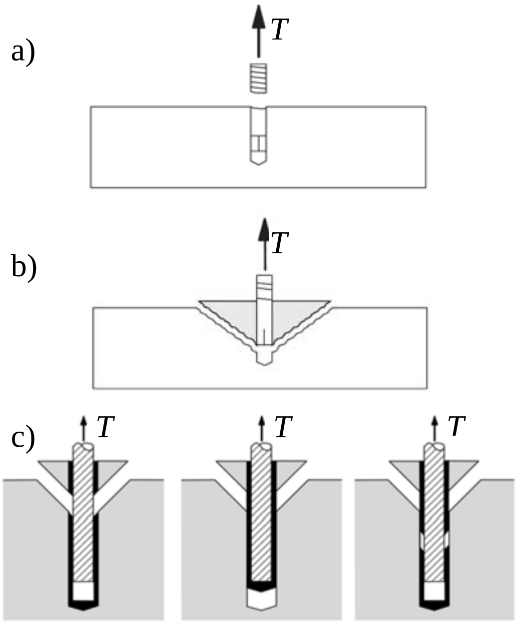

Figure 5: Failure modes of bonded anchors under tension load T: a) steel failure; b) concrete cone failure, c) bond failure; (Hoehler, 2006)

When using post installed anchoring systems these basic failure modes have to be taken into account. Due to the high ductility of steel, steel failure should be the governing failure mode which governs the tension capacity of the fastening.

3. COMPARISION OF JAPANESE AND EUROPEAN GUIDELINE

In order to compare the different calculation methods in the end of this chapter, first of all we have to consider two different safety concepts. In Europe the partial safety concept is already used while in Japan a global factor of safety is applied. In order to exclude the influence of those different safety concepts, the mean values of the ultimate loads are used in the following.

3.1. Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings in Japan

According to the *Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings*, 2001, the tensile capacity T_a is defined as the capacity resisted by a single anchor at the concrete interface. Tensile capacity shall be the smallest value of T_{a1} which is determined by steel strength, T_{a2} which is determined by concrete cone failure, and in case of bonded anchor additionally T_{a3} which is determined by bond strength.

$$T_a = \min (T_{a1}, T_{a2}, T_{a3}) \tag{1}$$

T_{a1}........ Tensile capacity of an anchor determined by yielding of steel material [N]
T_{a2}........ Tensile capacity of an anchor determined by concrete cone failure [N]
T_{a3}........ Tensile capacity of an anchor determined by bond failure [N]

3.1.1. Steel failure

Steel failure, sketched in Figure 5 (a), is calculated according to equation (2) by multiplication of the yield strength of the anchor and the cross section area.

$$T_{a1} = \sigma_y \cdot a_0 \tag{2}$$

σ_y.......... yield strength of anchor
a_0 .... effective cross section area of threaded steel bar, or nominal cross section area of anchorage bar [mm²]

3.1.2. Concrete cone failure

Anchorage for retrofitting is frequently applied in groups and close to the edge. Hence the projected area A_c (see Figure 6) usually is reduced. In order to exclude the influence of the different calculation methods of the projected areas, one single anchor without edge influence is taken into account in the following. As in the Japanese guideline just the capsule type adhesive anchor with a 45 degree cut bolt is taken into account, concrete cone failure can be calculated according to equations (3) - (5).

$$T_{a2} = 0.23\ \sqrt{\sigma_B}\ \cdot A_c \tag{3}$$

σ_B.......... concrete compressive strength of existing concrete [MPa], 150 mm x 300 mm cylinder
A_c.......... projected area of concrete cone failure surface of a single anchor [mm²] according to Figure 6

$$A_c = \pi \cdot l_e\ (l_e + d_a) \tag{4}$$

l_e........... effective embedment length of an anchor [mm]
d_a.......... nominal diameter of anchorage bar for bonded anchor

$$l_e = l - d_a \tag{5}$$

l............ embedment length of bonded anchor [mm]

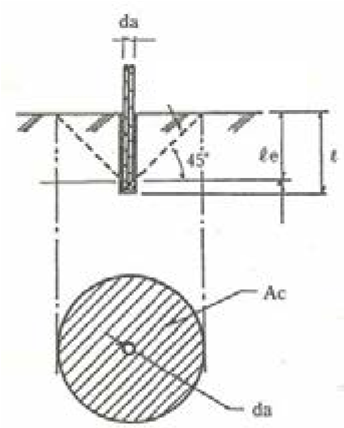

Figure 6: Projected area of concrete cone failure surface of a single anchor (45 degree cut bolt) A_c

3.1.3. Pull-out failure

The bond strength τ_a in equation (6) is calculated according to equation (7) in relation to the concrete compressive strength σ_B. Hence for pull-out failure, the true bond strength of the anchorage system is not fully utilized.

$$T_{a3} = \tau_a \cdot \pi \cdot d_a \cdot l_e \tag{6}$$

τ_a .... bond strength of bonded anchor against pull out force [MPa]

$$\tau_a = 10\sqrt{\sigma_B / 21} \tag{7}$$

3.2. Guideline for European Technical Approvals (ETAG)

Because of the traditional long term philosophy of buildings, there is a basic experience with cementitious materials (stone, masonry, concrete) and connectors in Europe. Furthermore solid contribution from the industry (e.g. the international federation for structural concrete "*fib*") with the normalizing institutions offers proper inclusion of state of the art concepts into the governing guidelines (ETAG 001, 2006).

3.2.1. Steel failure

As in chapter 3.1.1 steel failure is calculated according to equation (8) by multiplication of the yield strength of the anchor and the area of the cross section. Hence there is no difference in the two guidelines.

$$N_{u,s} = A_s \cdot f_y \text{ [N]} \tag{8}$$

$N_{u,s}$ .... ultimate load for steel failure (corresponds to T_{a1})
A_s .... stressed cross section of steel (corresponds to a_0)
f_y .... steel yield strength (corresponds to σ_y)

3.2.2. Concrete cone failure

Concrete cone breakout under axial loads is described in detail in the framework of the Concrete Capacity Design (CCD) Method (Fuchs e. al., 1995). Although the mechanical processes of this failure type is highly nonlinear, equation (9) can properly express the resulting ultimate resistance for a single anchor without influence of the boundary.

$$N_{u,c}{}^{0} = 13.5 \cdot \sqrt{f_{cc.200}} \cdot h_{ef}{}^{1.5} \tag{9}$$

$N_{u,c}{}^{0}$ ...... ultimate axial resistance of a single anchor for concrete cone failure (corresponds to T_{a2} without influence of edges or other anchors)
$f_{cc.200}$ .... 200 mm cube compressive strength of concrete [MPa]
$f_{cc.200} = 1.1875 \cdot \sigma_B$ (for strengths around 21 MPa)
h_{ef} .... effective anchor's length (corresponds to l_e)

3.2.3. Pull-out failure

The resistance in case of failure by pull-out, $N_{Rk,p}$, shall be taken from the relevant ETA (European Technical Approval). The calculation by equation (10) is similar to chapter 3.1.3 of the Japanese guideline, but by contrast according to the ETA every anchorage system has its own value of bond resistance τ_p.

$$N_{u,p} = \tau_p \cdot \pi \cdot d \cdot h_{ef} \tag{10}$$

$N_{u,p}$ .... ultimate load for pullout failure (corresponds to T_{a3})
τ_p .... bond resistance (corresponds to τ_a), taken from relevant ETA [MPa]
d .... diameter of anchor bolt or thread diameter (corresponds to d_a)

3.3. Comparison between Japanese and European guideline

As mentioned above, the different safety concepts are not taken into account in this comparison, hence only the mean values of the resistance of a single anchor in non-cracked concrete without edge influence are used.
Figure 7 shows a graph of the resistance T plotted against the nominal diameter of the anchorage bar d_a. In the Japanese design concept in the case of tension load the effective embedment length shouldn't be lower then 10 d_a. Hence the

embedment length is chosen to l_e = 10 d_a and a concrete compressive strength of σ_B = 21 MPa is used. An adhesive with a relatively low bond strength of τ_b = 15 MPa is applied. But even so, a large difference between the two guidelines is shown.

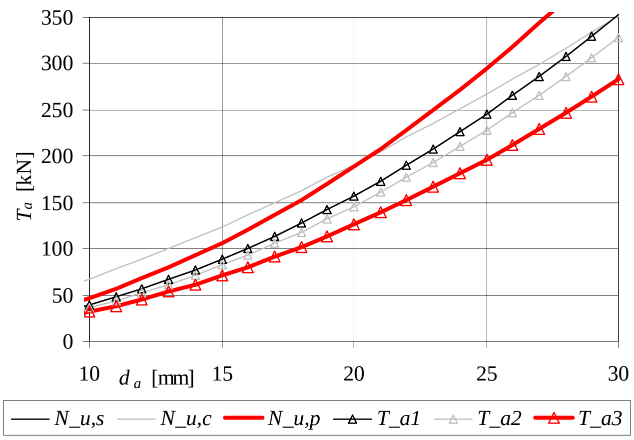

Figure 7: Comparison between guidelines in Japan (T) and Europe (N_u); σ_B = 21 MPa; l_e = 10 d_a; bond strength τ_b = 15 MPa; $T_{a1} = N_{u,s}$

3.3.1. Steel failure

In the case of steel failure the two guidelines, $N_{u,s}$ in equation (2) and T_{a1} in equation (8), get the same results and are plotted on the same line in Figure 7.

3.3.2. Concrete cone failure

The calculation of the resistance at concrete cone failure shows the first relevant difference. The Japanese curve of T_{a2} starts quite conservative at small diameters, but with increasing embedment depths the resistance rises faster compared to the European curve of $N_{u,c}$. This is caused by the consideration of the embedment length l_e to the power of 2 in the Japanese guideline equation (3) and (4) compared to 1.5 in the European guideline equation (9). At a diameter of d_a = 10 mm (l_e = 100 mm) the difference is quite significant; 46 %, however, for larger diameters of d_a = 30 mm (l_e = 300 mm) the discrepancy is reduced to 6 %, resulting in a more conservative estimation of ultimate capacity for shallower anchor embedments compared to deeper ones.

3.3.3. Pull-out failure

Qualitatively the major difference is the calculation of the pull out failure. In equation (7) of the Japanese guideline the bond strength of bonded anchor against pull out force τ_a is limited to 10 MPa at concrete strengths of σ_B = 21 MPa. It just has a smooth connection to different concrete strengths. The bond strength of the actual anchorage system is not taken into account.

By contrast the European guideline provides the bond strength given in the relevant ETA for each anchorage system. That way the calculated resistance and safety also depends on the specific adhesive anchoring system selected for the application. Consequently, the Japanese guideline forces bond failure to be the decisive failure mode at a level roughly 16% below the concrete cone capacity.

By contrast the European guideline allows the use of a system’s bond strength of 15 MPa to be taken into account. Due to the 50 % higher considered bond strength the curve is magnified by the same ratio for all diameters irrespective of embedment depths.

3.3.4. Decisive Failure

At this calculation according to the Japanese guideline the decisive failure mode is pull out failure, because the “true” bond strength of the selected anchorage system is disregarded.
In the case of earthquake the ductility should be a maximum. That means the desired decisive failure mode is steel failure. In order to achieve that steel failure governs the calculation, the concrete and bond capacity need to increase. That means deeper embedment depths, more options to hit a reinforcement bar or even the opposite edge.
According to the European guideline steel failure is the decisive failure mode for diameters between 8 and 29 mm and lays 20 % over the values of the Japanese guideline in the same diameter range.

4. CONCLUSION AND OUTLOOK

In numerous retrofitting applications for connections between steel and concrete, fastening by use of anchor bolts is often required. As connector between the existing and the new structure post installed anchorage is one of the important parts of retrofitting concerning strength, ductility and long-term behavior.

Comparing the Japanese and European guidelines the main differences are the following ones:

- The bond strength of a specific adhesive anchoring system is not taken into account at the Japanese guideline
- For concrete cone failures the Japanese guideline considers the embedment depth to the power of 2 instead of 1.5. With the conservative calculation of the Japanese guideline this way the safety of shallow embedment depths is higher than of deeper ones.
- At the Japanese guideline the decisive failure at $l_e = 10\ d_a$ is bond failure due to the bond strength limitation of 10 MPa in comparison to steel failure at the European guideline.

If there is a lack of guidelines, the executing engineer is responsible for the suitability and soundness of the connection, but in the case of bond failure, the existing Japanese guideline with the consideration of the low bond strength of 10 MPa, makes the calculation with higher bond strengths impossible. Better adhesive quality can be used for maintenance and retrofit reasons in structural as well as non-structural applications. That way many options of efficient use of post installed anchorage are denied which leads to fewer options and higher costs of retrofitting.
It should be possible to apply high sophisticated anchorage systems if they are needed by the executing engineer. That way also the developing of new fastening products is made attractive for the fastening industry. In Europe because of the easy accessible ETA, the executing engineer can choose the best suited system among an ample range of products. In Japan this process is limited and shows the need of an adapted guideline.

REFERENCE

CEN – European Committee for Standardization. CEN/TS 1992-4, 2009 Prestandard, *Design of fastenings for use in concrete*. Parts 4-1 to 4-5, Brussels.
Comitée Euro-International du Béton, 1995. *Fastenings for Seismic Retrofitting.* CEB Bulletin, Switzerland.
ETAG 001, Annex C, 2006, *Design Methods for Anchorages*.
Fuchs, W., Eligehausen, R. & Breen, J.R. 1995. *Concrete Capacity Design (CCD) Approach for Fastening to Concrete.* ACI Structural Journal V. 92, No.1 January - February 1995, pp. 73-94.
Hoehler, M.S., 2006. *Behavior and Testing of Fastenings to Concrete for use in Seismic Applications.* Dissertation, University of Stuttgart, Germany.
Hofmann, J., 2004, *Tragverhalten und Bemessung von Befestigungen unter beliebiger Querbelastung in ungerissenem Beton.* Dissertation. University of Stuttgart.
Mihala, R., Strauss, A., Bergmeister, K., Kränkel, T., Lowke, D., Schießl, P., 2009. *Durability and Reliability Assessment of Adhesive Anchors.* University of Natural Resources and Applied Life Sciences, Departmental Series Nr. 18, Vienna, Austria.
Tsuneo, O., Masaya, M. e.a., 2001. *Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings.* The Japan Building Disaster Prevention Association, Japan.

Web-based “Kobe JIBANKUN” System for the 1995 Kobe Earthquake Study

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ABSTRACT

The 1995 Kobe Earthquake has left us a great wealth of knowledge to further improve our earthquake engineering studies, especially on the strong ground motion at urban areas of the Kobe City and the liquefaction problems along the coast. The Kobe City has build a geotechnical database system, locally known as “Kobe JIBANKUN”, to study the cause of earthquake damages by gathering nearly 7000 boreholes and the earthquake damages data.
The “Kobe JIBANKUN” database has been until now built on a CD-ROM platform so that the study work can only be done on an individual computer basis, without the web sharing capability. A new web base system for “Kobe JIBANKUN” is built so that the earthquake engineering researchers can share and collaborate, and further promote the earthquake preparedness through working on this web based “Kobe JIBANKUN”. The system is built on open source programs so that a similar system can be easily developed without an excessive investment. This paper describes some examples of the use of the web based “Kobe JIBANKUN” to delineate the dynamic properties of inland and coastal grounds of the Kobe City, and also to promote the earthquake preparedness & awareness through a combined use of the web based database and the mobile terminals.

Keywords: *Great Hanshin Awaji Earthquake, geotechnical database, web-system*

1. INTRODUCTION

The Great Hanshin-Awaji Earthquake (or Hyogoken Nambu Earthquake) has hit the city of Kobe in early morning of January 17th, 1995. This was the first time in Japanese history after the Second World War to experience such a huge and devastating earthquake at a modern & well developed urban city. The Kobe City has suffered extensive earthquake damages due to the Earthquake, and the concentration of extremely heavy damages of residential houses along a narrow band of area within the City has resulted in a creation of the highest seismic intensity "Level 7" in JMA (Japan Meteorological Agency) scale.

The mechanism of earthquake damages, for example a study on narrow concentration of damages in the City, has been studied extensively by many researchers in Japan, including a research group in Kobe, "Research Group of Kobe Ground". This Kobe research group consisted of those from universities, practicing geotechnical engineers and administration officers in Kobe City Office, has started its research activities in 1998. The main focus of study of this group was to examine how the ground condition in the City has affected the variation of earthquake damages over the area, i.e., the local site effects. The research group has also made extensive use of geotechnical database, locally known as "KOBE JIBANKUN" that contained nearly 7000 borehole data in the City. Using this geotechnical database, dynamic response analyses have been made to examine the various earthquake damages in the City. Until now the "KOBE JIBANKUN" database has been built on a CD-ROM platform so that the study work can only be done on an individual computer basis, without the web sharing capability.

Because extensive earthquake damage and reconnaissance data are already available elsewhere for this 1995 Earthquake, the geotechnical dataset, which has previously not been publically available, is a remarkable collection to study the Earthquake. By disseminating the dataset in the context of the seismic hazard of the 1995 Kobe Earthquake through a web-based information system, there will be huge benefits to the research community, students, and practicing engineers. In view of this, a collaborative project has started in early 2009 between Tufts University and Kobe University to create a web based geotechnical database of the "KOBE JIBANKUN". The Japanese contents of the database and borehole logs were translated into English. When creating the web based database, additional geotechnical data of dynamic field testing, such as over 100 SASW (Spectrum Analysis of Surface Wave) test data obtained by the authors (Thompson 2010), were integrated into the database.

This paper discusses the use of "KOBE JIBANKUN" for the studies of earthquake engineering and also to promote the earthquake preparedness & awareness through an effective use of the information.

2. DYNAMIC PROPERTIES OF GROUNG BASED ON JIBANKUN

The methodology of carrying out an earthquake engineering study at a particular site can vary very significantly because there are many variables to consider, e.g., strong ground motion, landslides and/or liquefaction, and the site amplification alone can have various levels of analysis to be performed, e.g., simple method based on geomorphology to more sophisticated non-linear analysis by using soil models based on geotechnical studies. The information of damaged structures is also important, and its structural details need to be considered when the earthquake damage assessment is to be carried out.

Such integration of earthquake related information can be effectively made by using a GIS based digital information system, because the GIS system can provide

the users not only the geographic information at the point of interest but also other information together such as geotechnical, geological, geomorphologic and even historical & descriptive information of past earthquake damages.
Fig. 1 presents an example of web pages of “KOBE JIBANKUN” which is produced as a collaborative work between Tufts University and Kobe University. The figure presents the location of available boreholes and also SASW test sites over a seismic intensity variation map which was produced by Fujimoto and Midorikawa (1999). The number of boreholes is large enough to cover the entire area of Kobe City. In the figure, a 10 meter mesh digital elevation data of GSI

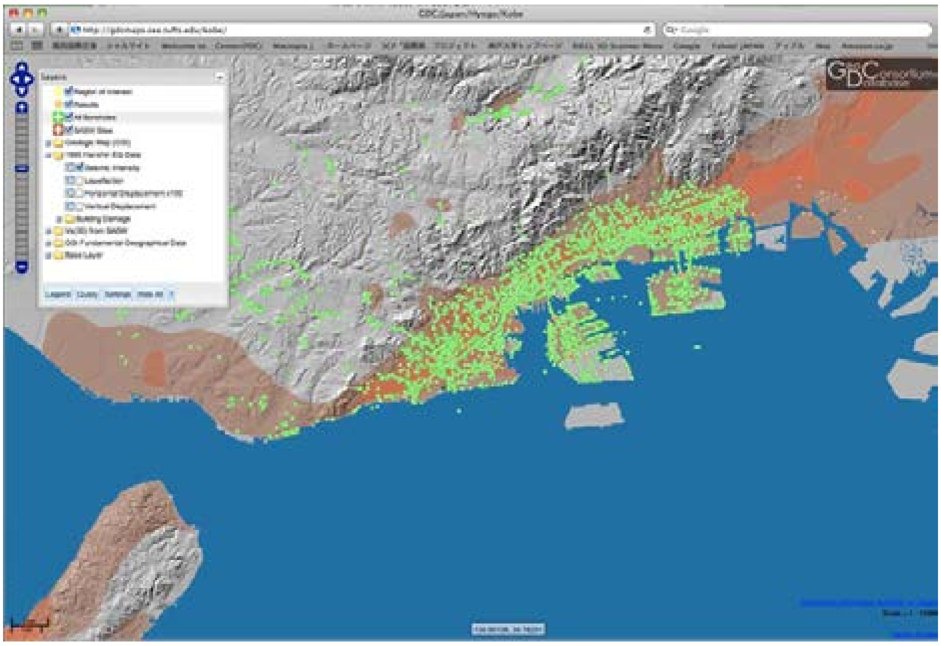


Figure 1: Location of boreholes and SASW sites with seismic intensity map

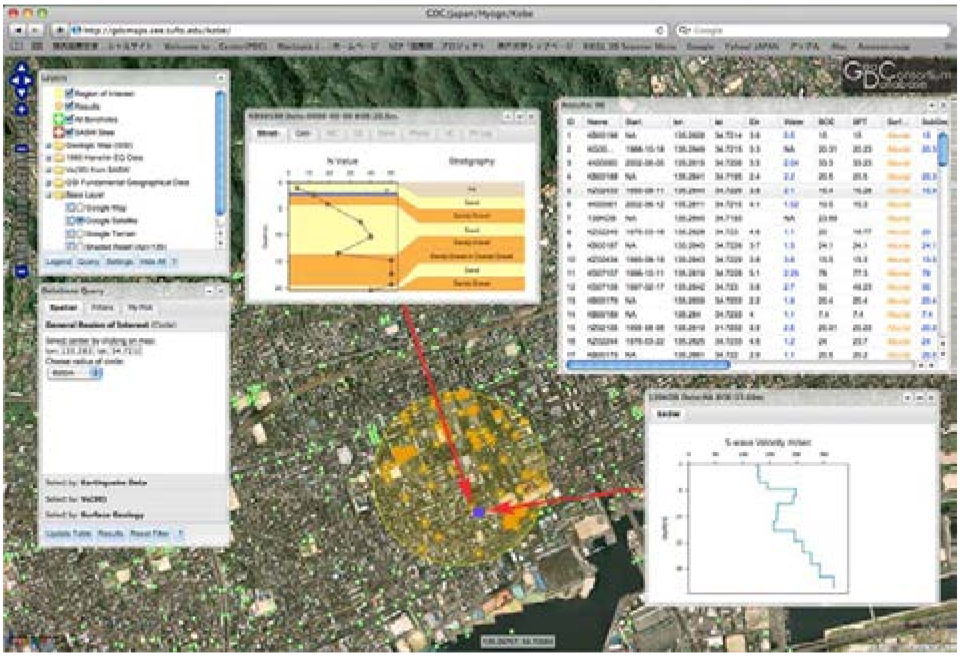


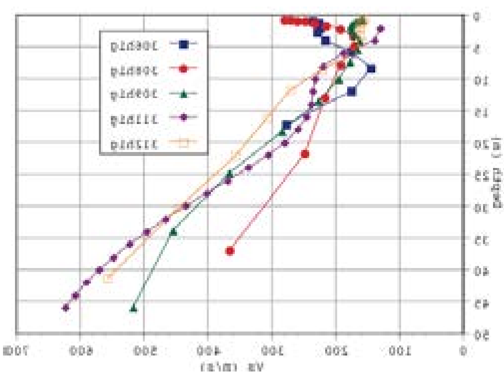
Figure 2: Location of boreholes and SASW sites in the Higashinada Ward

(Geospatial Information Authority of Japan) is used to illustrate the background topography, but various other publically digital map such as Google map & satellite can be used. Fig. 2 illustrates a comparison between a borehole data and a nearby SASW test at the eastern part of Kobe (i.e., Higashinada Ward). The depth variation of Vs can be cross-examined against the variation in soil stratigraphy.

2.1 Depth Profile of Vs Based on SASW test

The depth variation of Vs is a key information for studying the site amplification characteristics, but commonly such depth profile of Vs is not available at many places. As noted earlier, there have been extensive SASW tests being performed in this area so as to examine a local variation of Vs profile. Fig. 3 illustrates examples of examining the variation in Vs depth profiles at two different lines (i.e., one along the coastal area and the other at slightly inland from the coast).

Figure 3A: Lines of SASW test sites in the Higashinada Ward



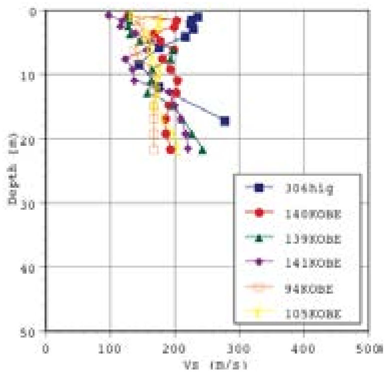


Fig. 3B: Vs depth profile at inland　　Fig. 3C: Vs depth profile along coast

Figs. 3B and 3C are produced by combining the SASW data along these two lines. It is clearly seen that at the coastal area, the Vs value is low and there is no significant increase of Vs with depth. Thus the seismic engineering base at the area near coast should be located at further depth. On the other hand, the Vs profile along the inland area away from coast increases significantly beyond a depth of 20 m and this depth can be set for the seismic engineering base for dynamic response analysis.

2.2 Correlation between Vs and SPT (N-value)

Although the delineation of dynamic property through the Vs profiling is more desirable, more commonly available soil data for studying the dynamic properties of ground is the N-value from the standard penetration test (SPT). Thus it would be useful to examine the relationship between the Vs value from the SASW and the N-value from borehole data. Examples of such correlation study are illustrated in Fig. 4 and Fig. 5 for the data available along the lines near the coast and the inland respectively. As can be seen from these figures, the Vs profile from the

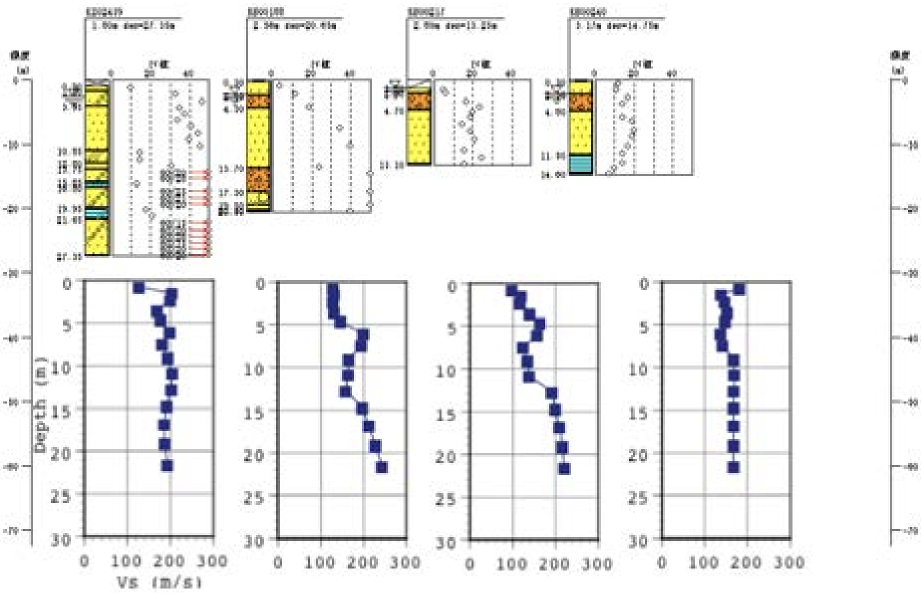


Figure 4: Comparison of N-value and Vs profiles along the coast

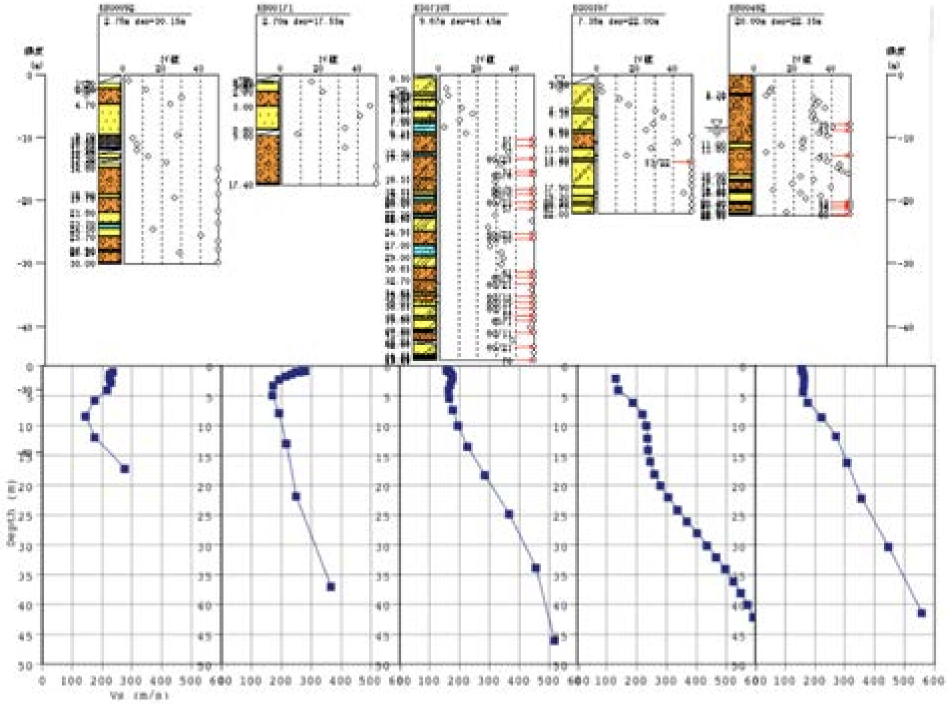


Figure 5: Comparison of N-value and Vs profiles along the inland

SASW indicate a gradual change of stiffness with depth, while the N-value profile indicate a rather scattering of stiffness changes. It is to be noted that the Vs profile from SASW test is obtained through a back analysis of surface wave transmission through elastic multi-layers, and therefore the gradual change of Vs with depth is inevitable. On the other hand, the scattering of N-value could also be affected by many unknown factors, such as inclusion of gravels or the dynamic nature of testing (e.g., the impact changes of falling head). Thus a good judgment is necessary to identify the true dynamic properties of ground from these test results. The correlation between the Vs value and the N-value can be more specifically identified by sorting the data for different soil types. Fig. 6 (a) & (b) present the correlations between the Vs and the N-value for the Holocene gravelly sand and for the Holocene sands respectively. Also included are the data points based on the previously available results (purple diamond in Fig. 6a, and hollow triangle in Fig.6b) through the Vs data obtained from the down-hole testing although the number of data points is much less. The Vs value as can be inferred from the new dataset seems to be slightly higher than those previously estimated.

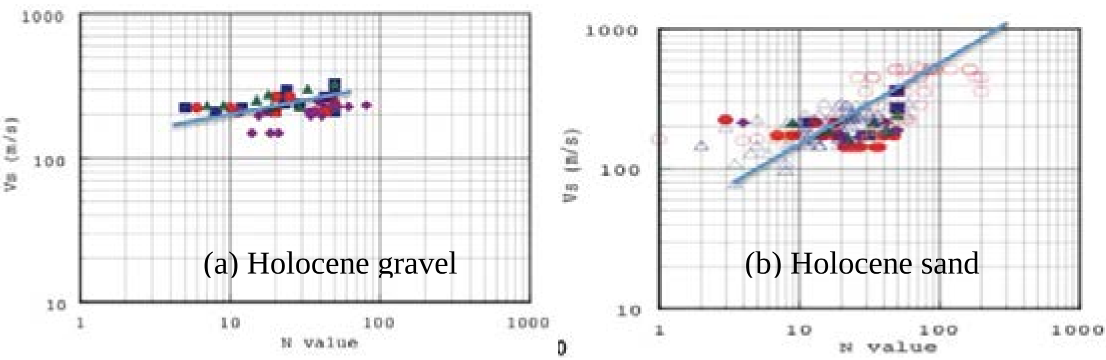


Figure 6: Comparison of N-value and Vs for the Holocene Gravel and Holocene Sand

3. USE OF WEB-BASED GEOTECHNICAL DATABASE FOR EARTHQUAKE RISK REDUCTION

The prime objectives of building a geotechnical database of the Great Hanshin-Awaji Earthquake is to share globally the engineering knowledge accumulated about the earthquake, geotechnical, and structural situations of the disaster. Through this global learning and research processes, it is hoped that the researchers, engineers, students, and moreover ordinary people can gain better knowledge on how to reduce future earthquake disasters. For such a wider spectrum of the target individuals to utilize this geotechnical database for different usages, the web-sharing capability of the data is essential, but also other capabilities such as user interface software and hardware of the database need to be carefully designed and developed. In the following sections, the present web system of current “KOBE JIBANKUN” is described and then possible future use of the database for the earthquake disaster risk reduction and preparedness & awareness is discussed.

3.1 Present Web System of KOBE JIBANKUN

The web system of KOBE JIBANKUN is built as a collaborative work between Tufts Univ. and Kobe Univ., and the details of the system can be found at a URL site of “gdc.cee.tufts.edu”. The web system is created by using open-source software as listed below, and the web page using current “OpenLayers” is not capable of handling “Multitouch” function for mobile tablet devices, such as iPad or other devices based on the Android operating system.

Table 1: Open source softwares and their functions

Software	Function
R	For statistical computing and graphics
ka-Map	A javascript API for developing highly interactive web-mapping interfaces
OpenLayers	JavaScript library for displaying map data in web browsers
MapServer	For generating images from the spatial database (stored in PostgreSQL)
PostgreSQL/PostGIS	Spatial database in PostgreSQL

3.2 Possible Interface Software and Hardware Developments

Presently, the Kobe Jibankun is mainly used by individual researcher to study the cause of earthquake damages by accessing to the geotechnical database. To more effectively use the database, a platform to exchange and share the knowledge gained through such research activities is required although the current webpage is created to perform this task. More recognition on the importance of building such geohazard database is needed, and similar activities need to be campaigned.
Also to fully utilize the potential of GIS system that store a large knowledge base, critical review is necessary as to its function. Fig. 7 is an example of potential usages of the web based GIS system, and the passive usage is mainly to retrieve

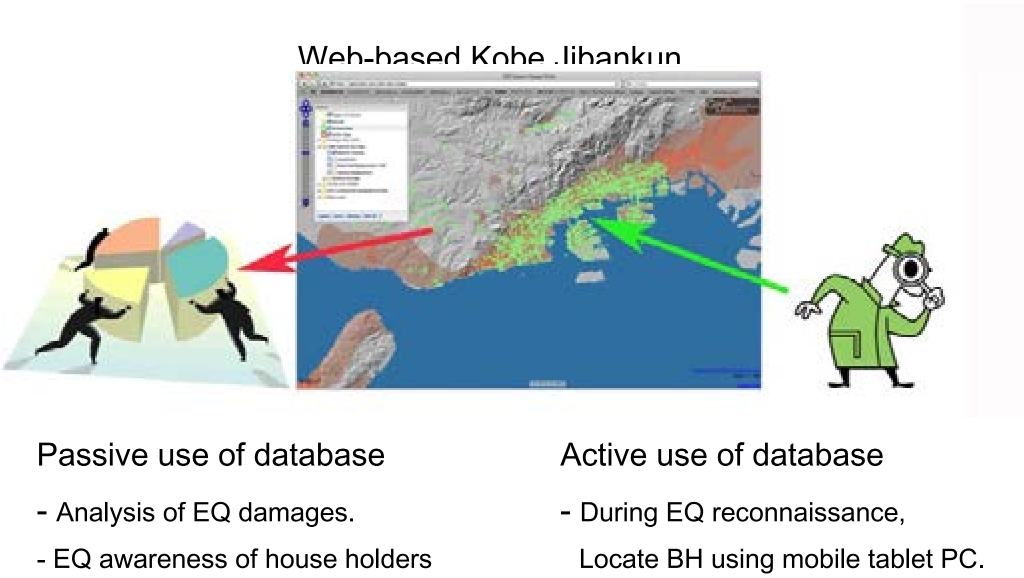


Figure 7: Active and passive usages of the GIS database

the data and the active usage is to use the GIS system, through a mobile tablet device, in finding the user's location and accessing interactively to the relevant data in the system. For the latter, a mobile device with GPS capability is most suitable. As noted earlier, current "OpenLayer" program does not have "Multitouch" function such as finger manipulations of touch screen and further improvements on the software interface are needed. After the introduction of iPad in 2010, a rapid development is taking place for similar mobile tablet devices based on "Android" OS and thus a new hardware interface may be developed especially for the active usage.

4. CONCLUSIONS

A web based geotechnical database that contains a huge dataset of the 1995 Great Hanshin Awaji Earthquake and relevant dynamic as well as static soil properties is created. Web dissemination of the dataset in the context of the seismic hazard study is hoped to be huge benefits to the research community, students, and practicing engineers. Some examples of using the database to examine the ground motion amplification properties are given by comparing the Vs profile from SASW and the N-value profile from borehole dataset.
Further developments to the present web based GIS system are needed both in software and hardware interfaces in order to fully be utilized as a tool for earthquake disaster risk reduction. Some discussion are made on the possible areas of future developments.

REFERENCES

Fuijmoto, K. and Midorikawa, S., (1999): Isoseismal map of the 1995 hyogo-ken nanbu earthquake estimated from damage distributions, Journal of structural and construction engineering. Transactions of AIJ (523), 71-78, 1999-09-30, Architectural Institute of Japan (in Japanese)

Thompson, E. M., Baise, L.G. Kayen, R.E., Tanaka, Y., Tanaka, H. (2010): A geostatistical approach to mapping site response spectral amplifications, Engineering Geology 114, pp 330–342

The mitigation strategy for Taiwan HSR passing through the land subsidence area of Yunlin County

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ABSTRACT

Yunlin County is located in the southwestern area of Taiwan, of which partial or whole areas of 13 out of 20 townships have serious land subsidence. This research uses the data of rainfall stations, groundwater monitor wells, and land subsidence monitor wells in Yunlin County to investigate whether climate change has affected Yunlin County's hydrological environment and its corresponding land subsidence. According to the land subsidence monitoring data of 2002, the greatest subsidence rates in the area which the HSR passes through was over 10 cm/yr. In order to reduce the extent of land subsidence along the HSR route, in 2005 the government chose specific areas to carry out a well sealing plan, which was to seal dozens of official wells at a distance of 1.5 kms on each side of the high speed rail (HSR) route. The plan was completed in 2008. From the actual land subsidence monitoring data of 2009, the greatest subsidence rates in the area which the HSR passes through was decreased from 10.6 cm/yr to 7.0 cm/yr. Thus limiting over pumping of groundwater has improved the land subsidence problem.

***Keywords**: climate change, land subsidence*

1. INTRODUCTION

The Taiwan High Speed Rail (HSR) is the most important transportation construction in recent years. HSR passes through the most part of western Taiwan including Taipei, Taoyuan, Hsinchu, Miaoli, Taichung, Changhua, Yunlin, Chiayi, Tainan, and Kaohsiung counties. The total length of HSR is 330 km and its highest speed is 300 km/hr. Figure 1 shows the HSR train entering into the station in Taichung.

Figure 1: HSR train and station

Because the speed of HSR is higher than a general train and the highway, the smoothness and stability of the HSR tracks are extremely important for safety. Any deformation of the HSR tracks must be controlled within an allowance range. HSR passes through the Chou-Shui Alluvial Fan, including Changhua County and Yunlin County. The soil layers of Chou-Shui Alluvial Fan have a high compression or consolidation potential. Groundwater is the primary water resource for irrigation, industry and urban demands. Land subsidence caused by continuance groundwater over pumping has been occurring in this region from 1970 to now. Unfortunately, HSR passes through the serious land subsidence area, including Huwei, Tuku, and Yuanchang in Yunlin County as shown in Figure 2. The differential settlement of the HSR tracks caused by land subsidence may impact the driving safety of HSR. This is a serious issue of utmost concern by the Taiwan government.

Climate change is an important factor of water resource management in the southwestern part of Taiwan including Yunlin County. The change of precipitation has confused the operation of the water supply systems in Yunlin County in recent years. The gap of water resources has always been satisfied with groundwater pumping. The demand of groundwater will be expectantly larger in the future, making the prevention of land subsidence even more difficult. A mitigation strategy is needed for the water resource management of Yunlin County to protect the driving safety of the HSR. Therefore, the Water Resources Agency (WRA) carried out a groundwater pumping reduction project from 2005 to 2007. The purpose of this project was to reduce yields of groundwater pumping in a banned region within a 3-km width along the HSR tracks in Yunlin County. As a result, several deep wells belonging to government agencies were decommissioned and sealed. The remaining wells are still being monitored to avoid groundwater over pumping. According to the land subsidence monitoring results from 2006, the improvement of preventing land subsidence was significant and showed that reduction of groundwater pumping was an effective strategy for conserving the safety of HSR.

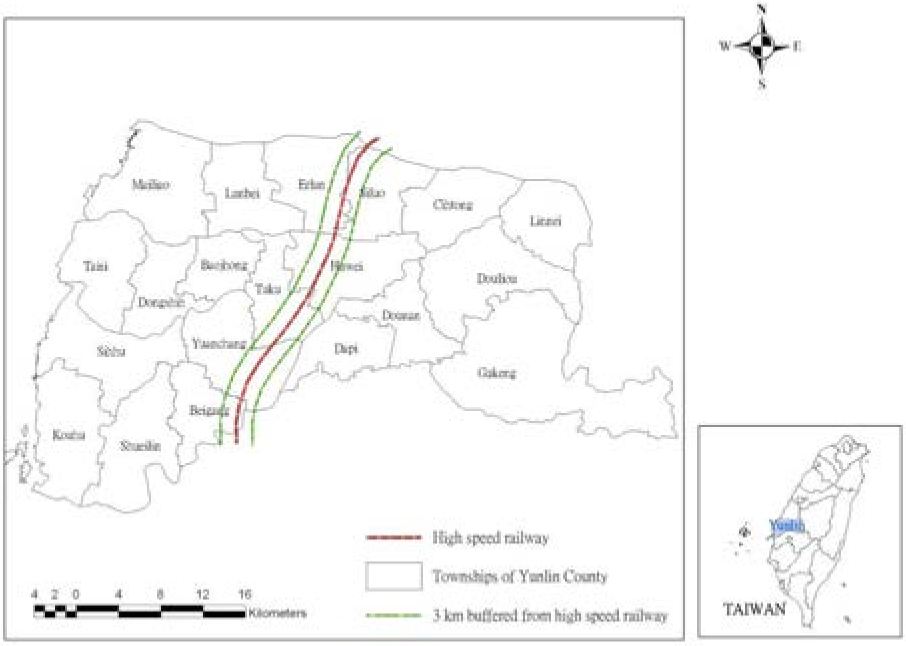

Figure 2: HSR route in Yunlin County

2. CLIMATE CHANGE IN YUNLIN COUNTY

The climate change phenomenon is discussed in this research using rainfall monitoring data from the Yunlin Irrigation Association. The period of rainfall records consists of 48 years, from 1961 to 2007. Those data can help us know the hydrology differences in Yunlin County of recent years. Figure 3 shows the accumulated rainfall per year at the Huwei and Huili rainfall monitoring stations. The linear regression shows accumulated rainfall per year has increased from 1961. The increased rates are 4.9 mm/year and 3.0 mm/year at the Huwei station and Huili station, respectively. In addition to the accumulated rainfall increase, Figure 3 also shows that the period between the wet years and dry years became shorter. For example, the time interval between the significant wet years of 1981 and 1990 was, in the past, nine years. But recently, the time interval has shorten to only four years between that of 2001 and 2005. The rainfall during the dry years was less than before, an evidence of climate change in Yunlin County. During the 29 years from 1961 to 1990, there were only two years, 1964 and 1980, where the accumulated rainfall per year was less than 1000 mm. But during the 17 years from 1990 to 2007, there were three significant dry years. Those phenomena show from the accumulated rainfall that rainfall will expectantly and dramatically change in Yunlin County in the future.

Figure 4 shows raining days per year from 1961 to 2007. According to the linear regression result of the data, the raining days per year did not increase significantly. The raining days per year did not reflect the increase of accumulated rainfall per year, which means that the rainfall intensity has increased. Therefore, there was higher rainfall intensity. The maximum average rainfall intensities were 24.8 mm/day and 25.18 mm/day at the Huwei station and Huili station, respectively. In recent years, the average rainfall intensities were higher than before, which means rainfall has become more concentrated in fewer days. This situation has impacted the water supply systems which essentially need a stable water resource.

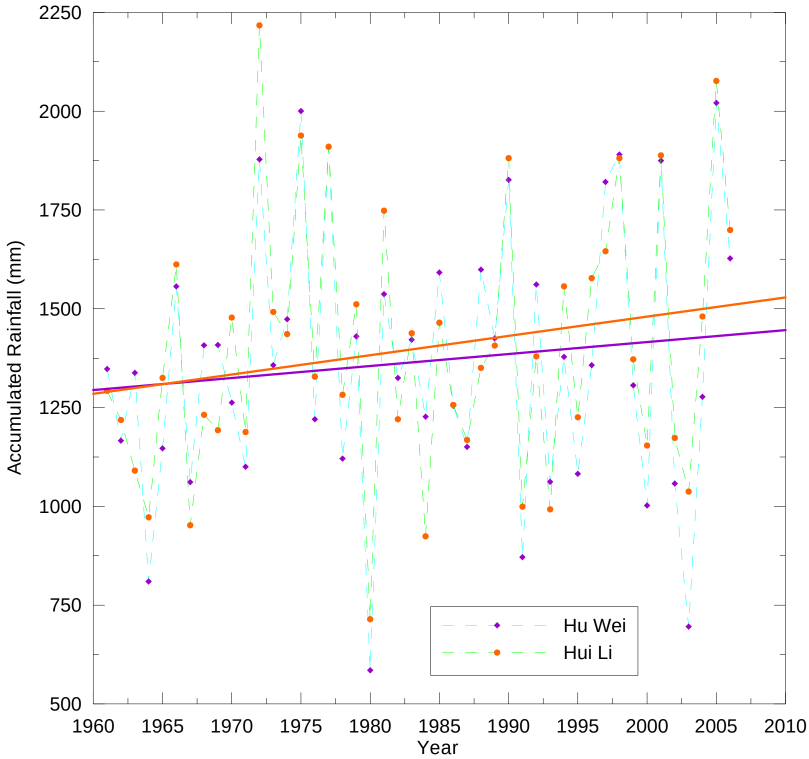

Figure 3: Rainfall per year in Yunlin County (1961-2007)

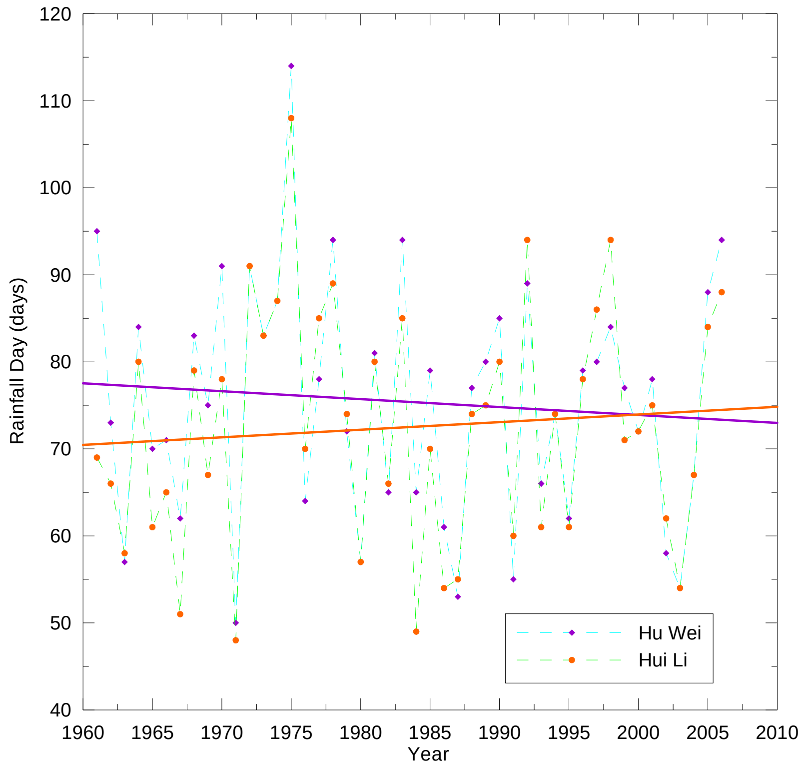

Figure 4: Raining days per year in Yunlin County (1961-2007)

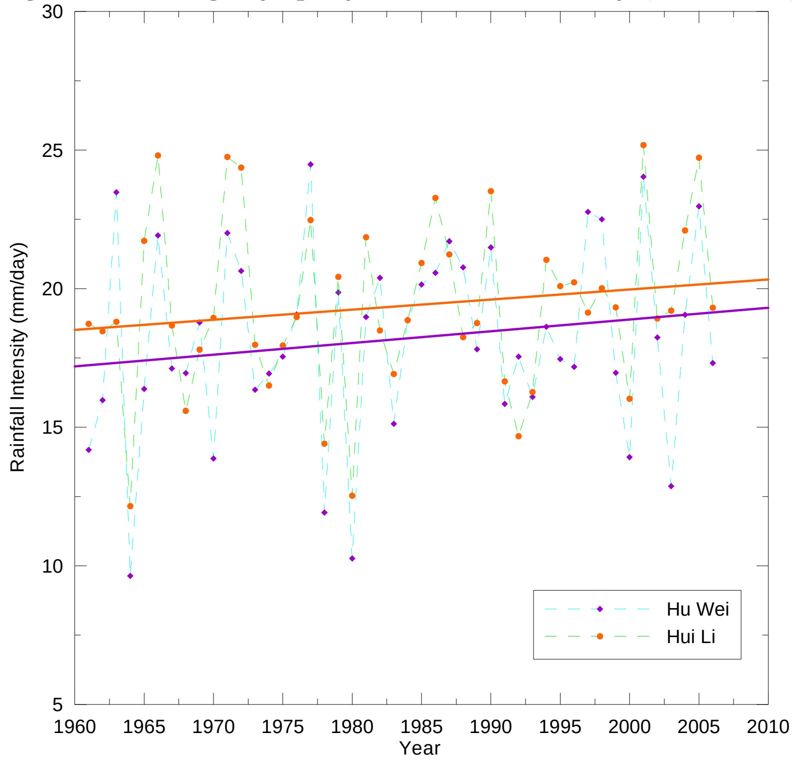

Figure 5: Rainfall intensity each year in Yunlin County (1961-2007)

3. WATER SUPPLY AND DEMANDS IN YUNLIN COUNTY

The major water supply systems in Yunlin County are the Taiwan Water Corporation and Yunlin Irrigation Association. The Taiwan Water Corporation usually supplies urban and industrial waters. The Yunlin Irrigation Association supplies irrigation water for farming. In addition to the Taiwan Water Corporation and Yunlin Irrigation Association, there are a large number of private wells in Yunlin County. According to the result of the general survey on wells, Yunlin County has over 11,000 wells. Figure 6 shows the water supply and demands from 2002 to 2021. The water supply and demands from 2002 to 2007 were actual records collected by the Taiwan Water Corporation, Yunlin Irrigation Association, and Water Resources Agency. According to these actual records from 2002 to 2007 and with the possible water resource exploitation in the future, the water supply and demands were estimated for 2011, 2016, and 2021. The actual records show that the water supply was less than the water demands from 2002 to 2007. The average gap of water resources in Yunlin County is 0.24 billion cubic meters. Even with expectations that the Hushan Reservoir will operate from 2014, the gap of water resources still will exceed 0.1 billion cubic meters in 2016 and 2021. It should be emphasized that the records of the water demands did not contain the yield of groundwater by all the private wells. The gap is larger than what the records show if groundwater pumping ceases in order to prevent land subsidence (WRA, 2009).

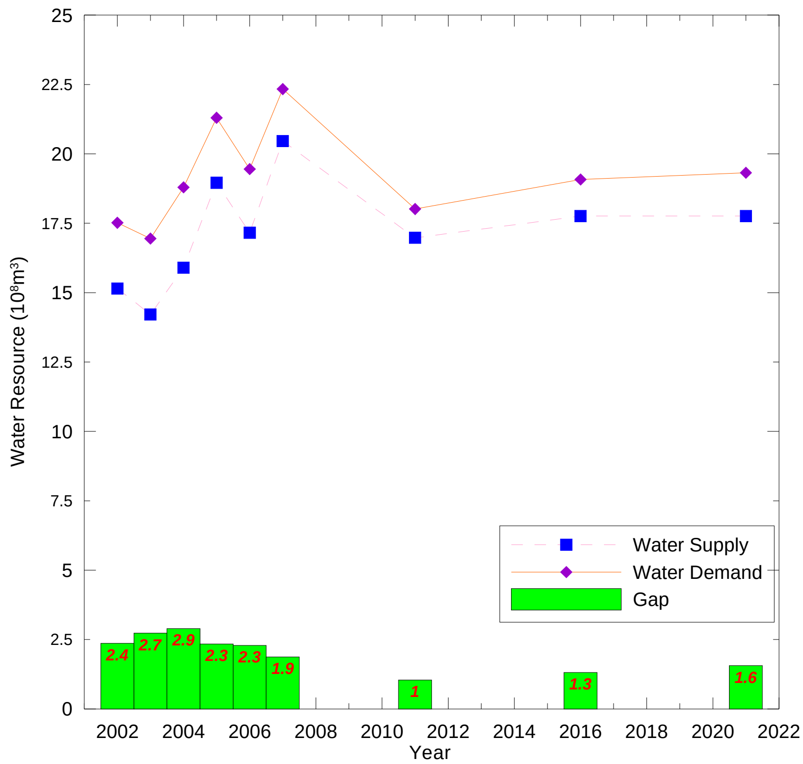

Figure 6: Water supply and demands in Yunlin County

4. Groundwater level variation

Groundwater level variation can reflect the groundwater over pumping effect. The decline of groundwater level of a region means the groundwater is continuously being over pumped. Figure 7 shows the groundwater level variation of four aquifer layers at the Husi groundwater level monitoring station near HSR. Before 2005, the groundwater declined significantly. During this period, groundwater was over pumped in this region. Not only was the groundwater level in decline for one aquifer layer, but also for all four aquifer layers, indicating that each aquifer layer was over pumped. The situation was really serious and land subsidence most likely occurred during this period. It also means that disequilibrium existed between the water supply and demands. But from 2005, the groundwater level near HSR increased and became stable. This means actions taken to prevent land subsidence were effective. Land subsidence has remarkably slowed down (Water Resources Agency, Consumptive Water Statistics Database).

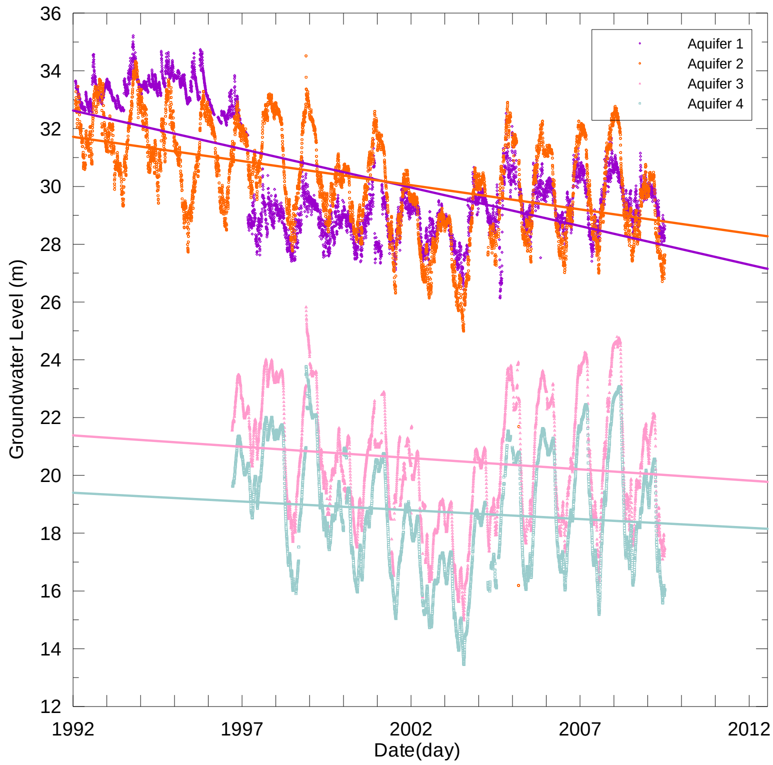

Figure 7: Groundwater level variation (Husi station)

5. LAND SUBSIDENCE ALONG HSR

The most serious areas of land subsidence are Tuku, Yuanchang, and Huwei. The route of HSR crosses these three villages. According to historical records, the maximum land subsidence rate was 12.2 cm/year in this region in 2002. However, the land subsidence rate has retarded in recent years. Figures 8, 9 and 10 show the subsidence rate of Yunlin County from 2006 to 2007, from 2007 to 2008, and from 2008 to 2009, respectively. The maximum subsidence rates were 8.2 cm/year, 7.1cm/year, and 7.4 cm/year during these three periods. It shows that the land subsidence of the regions along HSR has improved and the effort of reducing groundwater pumping may be the major reason for the improvement (Water Resources Agency, Land Subsidence Database).

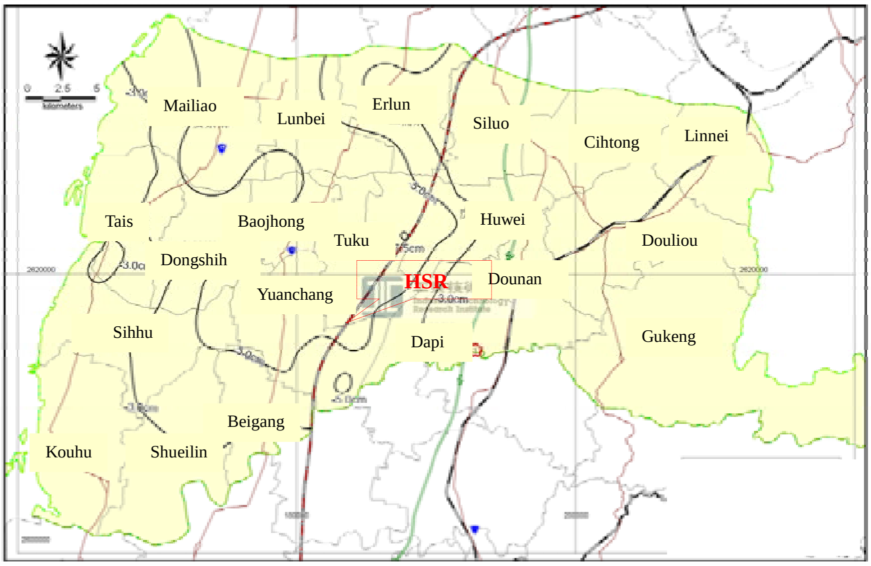

Figure 8: Land subsidence rate (2006-2007)

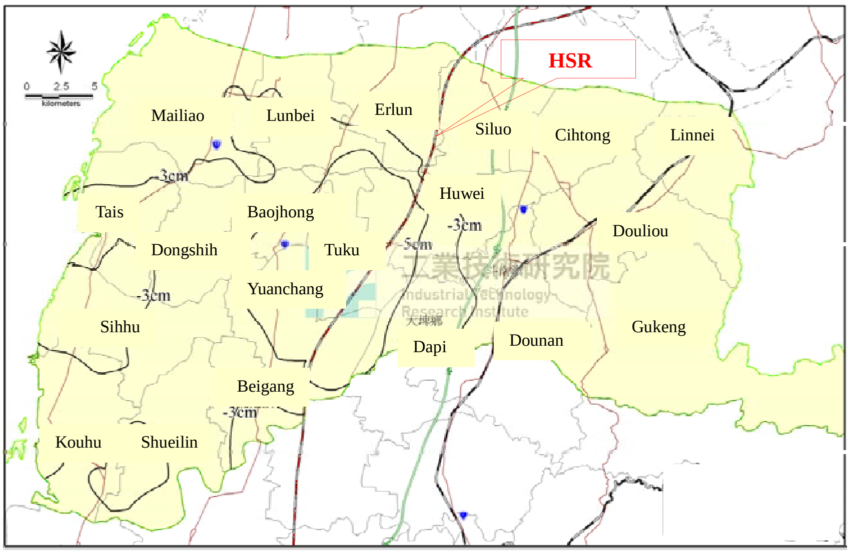

Figure 9: Land subsidence rate (2007-2008)

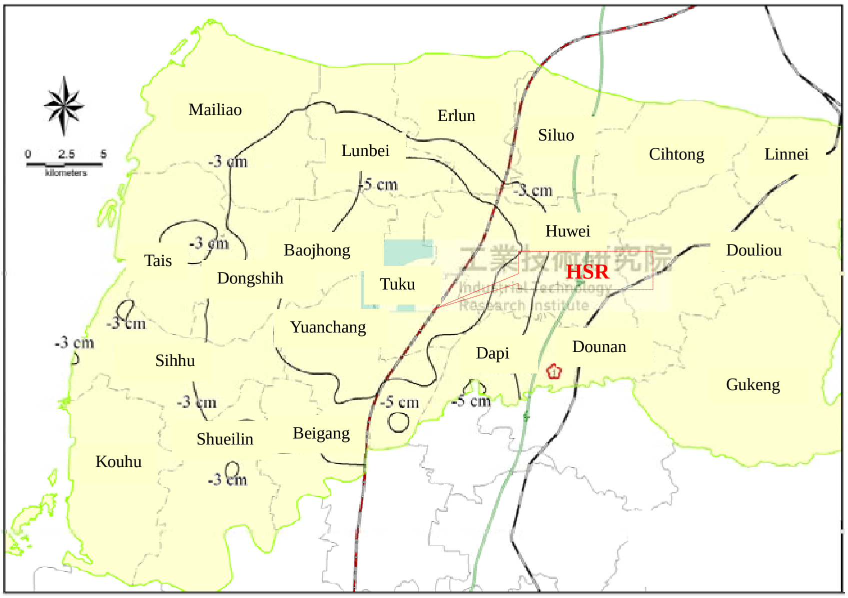

Figure 10: Land subsidence rate (2008-2009)

6. MITIGATION STRATEGY

In order to protect the driving safety of HSR, WRA carried out the “Project for Filling or Moving Wells of Government Agencies in Banned Regions within a 3-km Width along HSR in Yunlin County”. The project dealt with 69 wells of Yunlin Irrigation Association, 16 wells of Taiwan Water Corporation, and 2 wells of Taiwan Sugar Corporation. There were 29 wells filled, 39 wells that ceased pumping, and 19 wells monitored. Figure 11 shows the distribution of the wells that have been dealt with in this project. The reduction of the yield of groundwater was 400 million cubic meters per year in this project. The gap of water resource of this project was satisfied by allocating surface water from other vicinities. The land subsidence rate along HSR declined from 10.6 cm/year to 7.0 cm/year after this project. Also after this project, the threat from land subsidence for the safety of HSR was reduced. In order to respond to the climate change in Yunlin County, the Taiwan government must consider carrying out similar projects of reducing groundwater pumping (WRA, 2009).

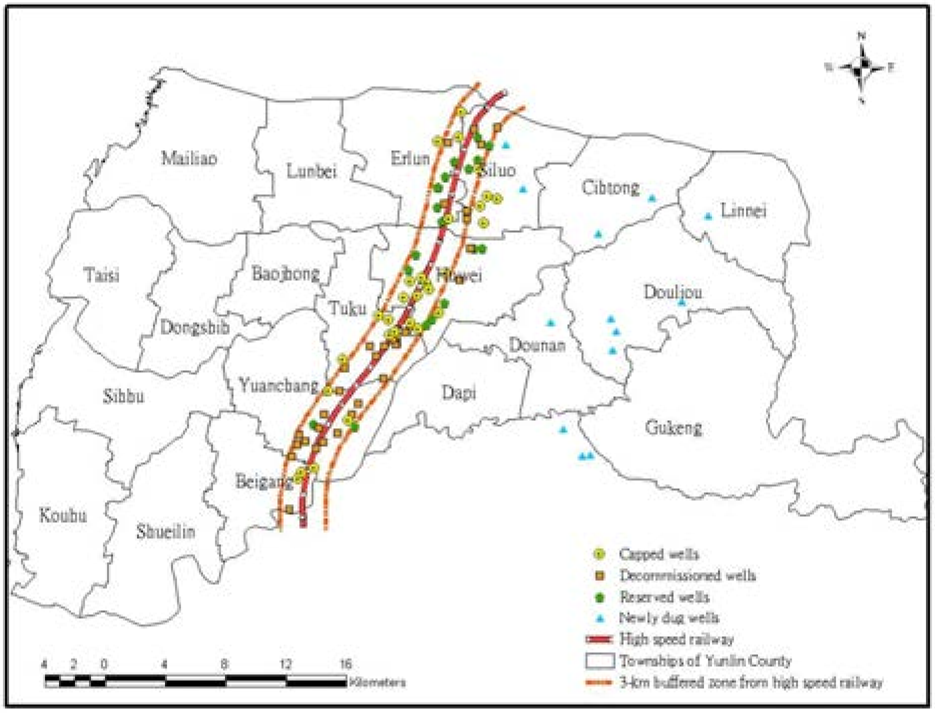

Fig. 11 Well distribution of the project

4. CONCLUSION

Climate change is happening in Yunlin County. The situation of water resources management will become sterner. In order to protect the driving safety of HSR, prevention of land subsidence in Yunlin County is urgent. How to reduce groundwater pumping is the most important issue for the government agencies. A rational strategy of surface water allocation should be generated and operated. The only way to decrease the rate of subsidence in Yunlin County is through reduction of groundwater pumping. The experiment, involving the well plugging projects of 2005, also confirms this opinion.

REFERENCES

Water Resources Agency, 2010. *Hydrological Year Book of Taiwan Republic of China 2009 Total Report*, Taiwan.

Water Resources Agency, 2009. *The feasibility study of multiple water resource development demands in Yunlin County*, Taiwan.

Water Resources Agency, 2009. The monitoring report of "Project for Filling or Moving Wells of Government Agencies in Banned Regions within a 3-km Width along HSR in Yunlin County", Taiwan.

Water Resources Agency, Consumptive Water Statistics Database. (http://wuss.wra.gov.tw/index.html. August 21, 2010 this site was reviewed.)

Water Resources Agency, Land Subsidence Database. (http://www.subsidence.org.tw/index2.aspx. August 21, 2010 this site was reviewed.)

Identifying Shape Characteristics of Hydrograph Components Based on Flood Disaster Mitigation

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ABSTRACT

This study investigates the characteristics of hydrograph components Based on flood disaster mitigation. Component hydrographs were modelled by a model of three serial tanks with one parallel tank. Mean rainfall was calculated using the block Kriging method. The seven parameters were calibrated using the shuffled complex evolution optimal algorithm and 38 events. Based on the analytical results, the findings were obtained: (1) For single-peak events, times to peak of hydrograph components are an increasing power correlation corresponding to peak time of rainfall; (2) The peak discharges of hydrograph components are linearly proportional to that of total runoff; the ratio for quick runoff is approximately 83% and 17% for the slow runoff; and (3) Relationships of total discharges also have direct ratios between hydrograph components and observed total runoffs; a quick runoff is 52% and 27% for a slow runoff. The remaining discharge is baseflow.

Keywords: block Kriging; linear cascade reservoir; streamflow components; hydrograph shape; runoff characteristic

1. INTRODUCTION

In the past, many hydrologists were interested in developments of rainfall-runoff conceptual models. Generally, approximations of the convolution integral are conveniently used to derive conceptual rainfall-runoff models and to generate outlet-runoffs of a watershed. These models derived from the convolution integral are generally known as UH-based modelling. These derivations with specific parameters are the Nash model (Nash, 1957), mathematical models (Clarke, 1973; Ahmad et al., 2009), geomorphologic IUH (Jin, 1992; Franchini & O'Connell, 1996; Nourani et al., 2009), the distributed parallel model (Hsieh & Wang, 1999), and subwatershed divisions (Agirre et al., 2005). Rainfall-runoff processes (O'Connell & Todini, 1996; Melone et al., 1998; Bhadra et al., 2010) have been modelled with IUH. Furthermore, changes of hydrograph characteristics on an urbanized watershed were also evaluated by identifying the relationships between IUH parameters and urbanization variables (Cheng & Wang, 2002; Cheng et al., 2008b; Huang et al., 2008a; Huang et al., 2008b; Kliment & Matoušková, 2009; Cheng et al., 2010).

Basically, essential materials of the UH-based models (e.g. Nash model) usually are recordings of rainfall and streamflow. Applying these models based on the

IUH theory involves determining both the effective rainfall and the baseflow of a rainfall-runoff event in advance. The baseflow, which is computed separately from the direct runoff, is a streamflow component and is frequently considered a constant in a rainfall-runoff event. Effective rainfall is the total rainfall deducting from the rainfall lost to depression storage, interception, evaporation and infiltration. Various works have addressed the effects of different methods for estimating rainfall excess and baseflow on the accuracy of modelling surface runoff (Mays & Taur, 1982; Cheng & Wang, 2002). Prior to IHACRES (Jakeman et al., 1990; Jakeman & Hornberger, 1993) and TANK (Sugawara, 1979; Sugawara, 1995; Madsen, 2000; Yue & Hashino, 2000; Hashino et al., 2002; Chen et al., 2003; Lee & Singh, 2005), hydrological modelling was not to generate total streamflow by a linear convolution with the specific input-output structures.

The assumptions of IUH like Nash's type linear reservoirs were preserved for the model used in this study, i.e., a uniform spatial distribution of rainfall and the principle of linear superposition. The model structure is serial cascades of three linear reservoirs and with one in parallel. Each linear reservoir has a kernel function with an exponential expression derived from the equation of continuity and convolution integral. These exponential expressions were used to illustrate storage statuses of the linear reservoirs during rainfall-runoff processes. Generating hydrograph components in a specific river during a storm is the first application of the proposed model with hydrological serial and parallel cascades. Then, the causal relationships among rainfall, total runoff observations, and generated runoff components were also discussed. The block Kriging method was used to estimate the mean rainfall as input for the model. Magnitudes of each open hole in the three serial reservoirs with one in parallel were defined as specific parameters and were acquired through an optimization approach. In the optimization processes, three evaluated criteria and an objective function were used to compare simulations and observations of total runoff hydrographs. The representative parameters are proportional to the magnitudes of the open holes and were used to determine surface, rapid subsurface, delayed subsurface and groundwater runoffs. Finally, hydrograph components (quick and slow flows) of the research watershed-outlet and their characteristics relating to observations of rainfall and total runoff were discussed and completed.

2. THE BLOCK KRIGING METHOD

The block Kriging method was used to estimate hourly spatially uniform rainfall over the whole watershed. The Kriging method is theoretically better than the Thiessen method because Kriging has a spatial structure (i.e., semivariogram), while Thiessen has a lesser ability to represent the spatial structure of rainfall.

2.1 Climatological Mean Semivariogram

A basic semivariogram called the scaled climatological mean semivariogram was proposed (Bastin et al., 1984) and established through dimensionless rainfall data on a project basin (Cheng et al., 2007). The relationship between the experimental semivariogram and the scaled climatological mean semivariogram is shown below:

$$\gamma(t,h_{ij}) = \omega(t)\gamma_d^*(h_{ij},a) = s^2(t)\gamma_d^*\left(h_{ij},a\right) \quad (1)$$

where $\omega(t)$ denotes the sill of the semivariogram for time period t (mm^2) and is time-variant; a represents the range of the scaled climatological mean semivariogram (m) and is time-invariant; and $s(t)$ denotes the standard deviation of rainfall of all raingauges for time period t (mm). The basic semivariogram is expressed as

$$\gamma_d^*\left(h_{ij},a\right) = \frac{1}{2T}\sum_{t=1}^{T}\left\{\left[\frac{p(t,x_i)-p(t,x_j)}{s(t)}\right]^2\right\} \quad (2)$$

The basic experimental semivariogram can be calculated by using equation 6. Because this semivariogram is derived from discontinuous point-observations, it is not spatially continuous. A realistic application for a block Kriging method is to use a popular semivariogram model, named the power model, to obtain spatial continuity of rainfall variations in Taiwan. The equation for the power model is expressed as

$$\gamma_d^*(h_{ij},a) = \omega_0 h_{ij}^a, \quad a < 2 \quad (3)$$

where ω_0 denotes the sill of the scaled climatological mean semivariogram (mm^2) and is a constant of approximately one except for the power model.

2.2 Block Kriging System

The block Kriging method obtains optimal weights that are obtained from the Kriging system by assuming a given spatial structure of rainfall. The system is derived by applying Lagrange's multipliers. The estimated area V must be divided into M grids before calculating the hourly mean rainfall of storm events over the watershed by applying equation 4

$$\begin{cases} \sum_{j=1}^{n}\lambda_j\gamma(x_i,x_j) + \mu = \frac{1}{M}\sum_{m=1}^{M}\gamma\left(V_m,x_i\right), \; i = 1,2,\ldots,n \\ \sum_{i=1}^{n}\lambda_i = 1 \end{cases} \quad (4)$$

$$\sigma_K^2 = \sum_{i=1}^{n}\lambda_i\bar{\gamma}(V,x_i) + \mu \quad (5)$$

where $\gamma(x_i,x_j)$ is the semivariogram of raingauge x_i and raingauge x_j (mm^2); V_m is the m-th grid in the estimated area; $\bar{\gamma}(V_m,x_i)$ represents the average semivariogram of estimated area V and raingauge x_i (mm^2); λ_i is the weighting of each raingauge; σ_K^2 is the Kriging estimated variance (mm^2); and μ denotes the Lagrange's multipliers (mm^2). The estimator Z_K^* of the hourly mean rainfall is a linear combination of n available point-rainfall recordings $Z(x_i)$ located at x_i and with weightings λ_i. The Kriging estimator can be expressed as

$$Z_K^* = \sum_{i=1}^{n} \lambda_i Z(x_i) \tag{6}$$

3. THE MODEL OF LINEAR CASCADE RESERVOIRS

The model in this study is constructed from three linear serial reservoirs with one in parallel. These reservoirs are individually viewed as independent systems by following the hydrological cycle. The inputs and outputs of linear systems are analogous to natural flows as runoff components and infiltration. The convolution integral was used to describe the interior transformations of independent systems for the inputs and outputs.

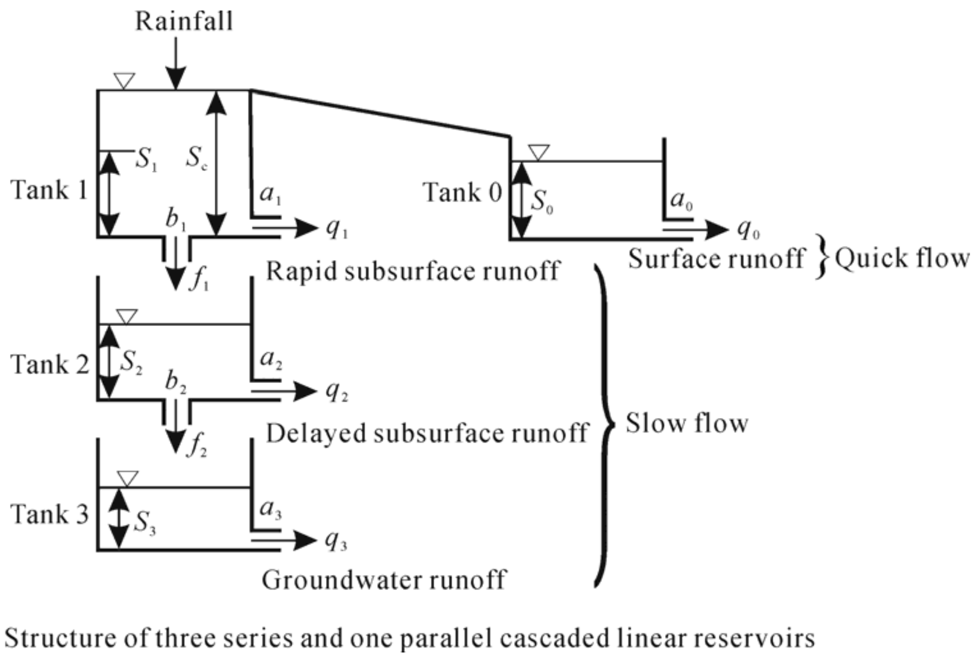

Figure 1: The model structure of three serial reservoirs with one in parallel

3.1 Structure and Flow Mechanism within the Model

The proposed model is a lumped rainfall-runoff model for single-input and multiple-outputs. Average rainfall is the single input for the whole model system, while the outputs are surface, subsurface and groundwater runoffs at the watershed outlet. Subsurface runoff is divided into rapid and delayed subsurface runoffs. This model (Figure 2) has one horizontal open hole and a vertical opening in the upper and middle reservoirs in serial (Tank 1 and Tank 2), while the parallel reservoir (Tank 0) and the lowest serial reservoir (Tank 3) only have a horizontal opening. The rates at which water moves through the opening for the horizontal holes of one parallel and three serial reservoirs are denoted as a_0, a_1, a_2 and a_3, while b_1 and b_2 are for the vertical holes of the upper and middle reservoirs in serial, respectively. Flow discharges, q_1, q_2 and q_3, of the horizontal holes at the bottom of the three serial reservoirs are modelled as rapid subsurface, delayed subsurface and groundwater runoffs. The analogous meaning of surface runoff is indicated by flow q_0 of a horizontal opening of the parallel reservoir when storage in the upper reservoir in serial is higher than the height S_c itself. Height S_c can describe the soil antecedent moisture before rainfall. Infiltration amount f_1 flows from a vertical hole in the upper reservoir to the middle reservoir in serial. Discharge f_2 represents the amount of percolation coming from the deep soil aquifer, flowing from the middle reservoir to the lowest reservoir in serial.

Rainfall r first falls into the upper reservoir in serial (Tank 1), which begins storing this rainwater (i.e., $S_1 > 0$). The rapid subsurface runoff q_1 and infiltration f_1 are simultaneously produced and flow out of the upper reservoir in serial. When the storage height of the upper reservoir in serial exceeds height S_c (Tank 1 is full), overflow occurs from the upper reservoir in serial (Tank 1) to the parallel reservoir (Tank 0) and surface runoff q_0 is generated, i.e., $S_1 > S_c$. Infiltration f_1 enters the middle reservoir in serial (Tank 2) and is stored, and the delayed subsurface runoff q_2 and percolation f_2 then start flowing ($S_2 > 0$). Finally, percolation f_2 flows into the lowest reservoir in serial (Tank 3), and its storage status is the same as that in the middle reservoir in serial; and groundwater q_3 flows away from the lowest reservoir in serial.

3.2 Storage Functions over Time

According to the flow mechanism of the model, runoff components q_1, q_2, q_3, infiltration f_1 and percolation f_2 are storage functions of three reservoirs in serial, whereas surface runoff q_0 is the amount which overflows from the upper reservoir in serial into and out of the parallel reservoir. These outflows, except surface runoff q_0, are expressed as follows:

$$q_i(t) = a_i S_i(t), \quad i = 1, 2, 3 \text{ (mm/hr)} \tag{7}$$

$$f_i(t) = b_i S_i(t), \quad i = 1, 2 \text{ (mm/hr)} \tag{8}$$

By combining the equation of continuity and the convolution integral, the storage functions can be obtained from specific inputs of three serial reservoirs with a parallel reservoir. That is, the IUH for one input unit. The input unit of the upper reservoir in serial is the rainfall that occurred between 0 and Δt (the value of Δt depends on the recording interval for the rainfall data; in this study, it is 1 hour) and that of the other time periods is zero. Hence, instantaneous input $I_1(t)$ equals $1/\Delta t$, and $C_1 = a_1 + b_1$; thus, storage height $S_1(t)$, which is less than S_c, of the unit input for the upper reservoir in serial can be derived as follows:

$$S_1(t) = \frac{1}{\Delta t}\frac{\left(1 - e^{-C_1 t}\right)}{C_1}, \quad 0 < t \le \Delta t \tag{9}$$

$$S_1(t) = \frac{1}{\Delta t}\frac{\left(e^{C_1\Delta t} - 1\right)e^{-C_1 t}}{C_1}, \quad t > \Delta t \tag{10}$$

Similarly, unit input $I_2(t)$ of the middle reservoir in serial is the infiltration output $f_1(t)$ of the upper reservoir in serial, i.e., $I_2(t) = f_1(t) = b_1 S_1(t)$, and $C_2 = a_2 + b_2$; thus, storage height $S_2(t)$ of the unit input for the middle reservoir in serial is as follows:

$$S_2(t) = \frac{1}{\Delta t}\frac{b_1}{C_1 C_2}\left[1 + \frac{C_2}{C_1 - C_2}e^{-C_1 t} - \frac{C_1}{C_1 - C_2}e^{-C_2 t}\right], \quad 0 < t < \Delta t \tag{11}$$

$$S_2(t) = \frac{1}{\Delta t}\frac{b_1}{C_1 C_2}\left[\frac{-C_2\left(e^{C_1\Delta t} - 1\right)}{C_1 - C_2}e^{-C_1 t} + \frac{C_1\left(e^{C_2\Delta t} - 1\right)}{C_1 - C_2}e^{-C_2 t}\right], \quad t > \Delta t \tag{12}$$

Finally, the unit input of the lowest reservoir in serial is $I_3(t) = f_2(t) = b_2 S_2(t)$, and $C_3 = a_3$; thus, the mathematical expression of storage height $S_3(t)$ of the lowest reservoir in serial is expressed as

$$\begin{aligned} S_3(t) = \frac{1}{\Delta t}\frac{b_1 b_2}{C_1 C_2 a_3}\Bigg[1 - \frac{C_2 a_3}{(C_1 - C_2)(C_1 - a_3)}e^{-C_1 t} + \frac{C_1 a_3}{(C_1 - C_2)(C_2 - a_3)}e^{-C_2 t} \\ - \frac{C_1 C_2}{(C_1 - a_3)(C_2 - a_3)}e^{-a_3 t}\Bigg], \quad 0 < t \le \Delta t \end{aligned} \tag{13}$$

$$\begin{aligned} S_3(t) = \frac{1}{\Delta t}\frac{b_1 b_2}{C_1 C_2 a_3}\Bigg[\frac{C_2 a_3\left(e^{C_1\Delta t} - 1\right)}{(C_1 - C_2)(C_1 - a_3)}e^{-C_1 t} - \frac{C_1 a_3\left(e^{C_2\Delta t} - 1\right)}{(C_1 - C_2)(C_2 - a_3)}e^{-C_2 t} \\ - \frac{C_1 C_2\left(e^{a_3\Delta t} - 1\right)}{(C_1 - a_3)(C_2 - a_3)}e^{-a_3 t}\Bigg], \quad t > \Delta t \end{aligned} \tag{14}$$

Similar to the upper reservoir in serial (Tank1), for the unit input ($I_0 = 1$) in duration Δt, the unit pulse response function of the parallel reservoir, which is used to generate surface runoff q_0, can be obtained as

$$u_0(t) = \frac{1 - e^{-a_0 t}}{\Delta t}, \quad 0 < t \le \Delta t \tag{15}$$

$$u_0(t) = \frac{1}{\Delta t}\left(e^{a_0\Delta t} - 1\right)e^{-a_0 t}, \quad t > \Delta t \tag{16}$$

3.3 Parameter limitations

Based on physical significances of the principles of the hydrological cycle, soil infiltration and runoff generation, the model parameters should be confined to the following seven limitations:

1. $a_0 > a_1$, rate coefficient of surface runoff q_0 should be larger than that of rapid subsurface runoff q_1;
2. $a_1 \geq a_2$, rate coefficient of rapid subsurface runoff q_1 is larger than that of delayed subsurface runoff q_2;
3. $a_2 > a_3$, rate coefficient of delayed subsurface runoff q_2 is larger than groundwater amount q_3;
4. $b_1 > b_2$, rate coefficient of infiltration f_1 resulting from the upper reservoir should be larger than that of percolation f_2 coming from the middle reservoir;
5. $1-(a_1+b_1) \geq 0$, sum of two opening ratios in the upper reservoir in serial shouldbe less than or equal to 1;
6. $1-(a_2+b_2) \geq 0$, sum of two opening ratios in the middle reservoir in serial is less than or equal to 1;
7. $1-a_3 \geq 0$, the opening ratio of the lowest reservoir in serial is less than or equal to 1, and
8. $1-a_0 \geq 0$, the opening ratio of the parallel reservoir is less than or equal to 1.

4. EVALUATION CRITERIA

This study utilized three criteria to evaluate the suitability of the rainfall-runoff model for the basin of interest. These three criteria are as follows:

1. Coefficient of efficiency, CE, is defined as

$$CE = 1 - \frac{\sum_{t=1}^{T}\left[Q_{est}(t) - Q_{obs}(t)\right]^2}{\sum_{t=1}^{T}\left[Q_{obs}(t) - \overline{Q}_{obs}(t)\right]^2} \tag{17}$$

where $Q_{est}(t)$ denotes the discharge of the simulated hydrograph for time period *t*, $Q_{obs}(t)$ is the discharge of the observed hydrograph for time period *t*, and $\overline{Q}_{obs}(t)$ is the average discharge of the observed hydrograph for time period *t*. The better the fit, the closer CE is to one. A negative value for CE means that model predictions are worse than predictions using a constant that is equal to the average observed value.

2. The error of peak discharge, $EQ_p(\%)$, is defined as

$$EQ_p(\%) = \frac{Q_{est,p} - Q_{obs,p}}{Q_{obs,p}} \times 100\% \tag{18}$$

where $Q_{est,p}$ is the peak discharge of the simulated hydrograph and $Q_{obs,p}$ is the peak discharge of the observed hydrograph.
3. The error of the time for peak to arrive, ET_p, is defined as

$$ET_p = T_{est,p} - T_{obs,p} \tag{19}$$

where $T_{est,p}$ is the time for the simulated hydrograph peak to arrive and $T_{obs,p}$ is the time required for the observed hydrograph peak to arrive.

5. WATERSHED DESCRIPTION

5.1 Geographical feature

The upstream area of the Wu-Tu Watershed was chosen to explore the characteristics of runoff components resulting from the model of three serial cascade reservoirs with a parallel reservoir in the research area. The watershed surrounds Taipei city in the northern part of Taiwan (Figure 2). The Wu-Tu Watershed covers about 204 km^2, and the mean annual precipitation and runoff depth are 2865 mm and 2177 mm, respectively. Due to the rugged topography of the watershed, runoff pathlines are short and steep, and rainfall is not uniform in terms of both time and space. Large floods arrive rapidly in the middle-to-downstream reaches of the watershed, causing serious damage during summers.

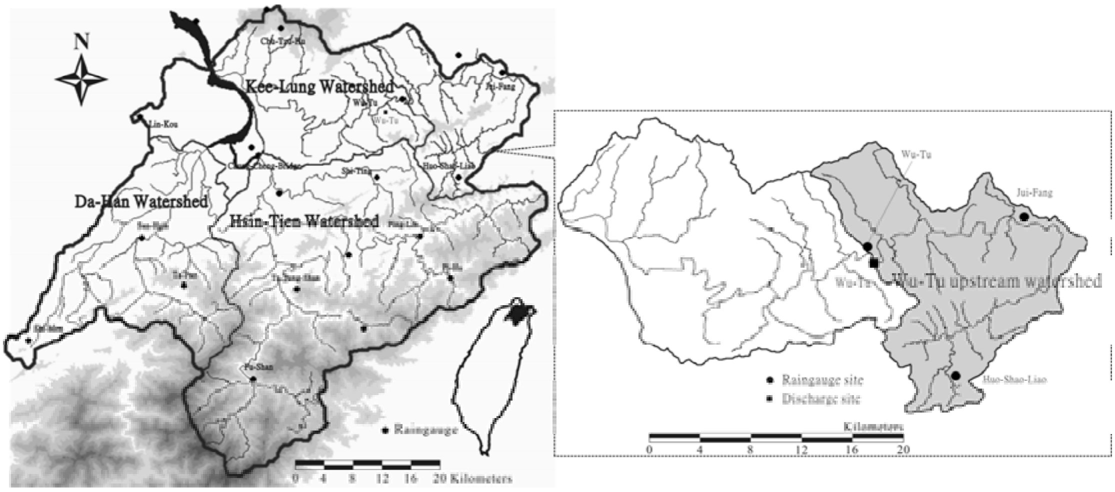

Figure 2: Location maps of the Tamshui River Basin and the Wu-Tu watershed

5.2 Rainfall-runoff material

There are three raingauges (Jui-Fang, Wu-Tu and Huo-Shao-Liao) and one discharge site (Wu-Tu) on the upstream portion of the Wu-Tu Watershed. The recorded 38 rainfall-runoff events of 1966-2008 were used as the study sample. The sample of events includes 5 multi-peak events, whereas the remaining ones are single-peak events. In total, 38 cases were selected for parameter calibration. The spatial variations of rainfall (i.e., semivariogram in the block Kriging method) were analyzed using the data from the 14 raingauges (including those at Jui-Fang, Wu-Tu and Huo-Shao-Liao) (Figure 2) located in and around the upstream portion of the Wu-Tu Watershed. Hourly inputs of mean rainfall for the model were estimated using the analyzed semivariogram, Kriging system and three raingauges (i.e., Jui-Fang, Wu-Tu and Huo-Shao-Liao) located in the Wu-Tu watershed.

6. Results and Discussions

This study initially attempts to generate runoff components on a watershed outlet. Translating single-input (rainfall) into multi-output (streamflow components) depends on the lumped model of three serial reservoirs and one in parallel. Streamflow components during a rainfall-runoff event are generally divided into surface, subsurface and groundwater runoffs. Subsurface runoff can be further divided into rapid and delayed subsurface runoffs. This section evaluates model applicability based on calibration results and generation of streamflow components. This study also analyzes the characteristics of outlet-hydrograph components of the Wu-Tu watershed during rainfall-runoff processes. The quick runoff (surface runoff) and slow runoff (a sum of the subsurface and groundwater runoff) are discussed herein. Restated, this section examines the characteristics of quick and slow flows related to observations of rainfall and total runoff hydrographs. Runoff characteristics that are compared include the time to peak, peak discharge and total discharge.

6.1 Model calibration

The hourly semivariogram is a function of time t, isotropy, and a time average form with a nonzero and T time interval. The analytical results of the scaled climatological mean semivariogram for the 38 rainfall events recorded by 14 raingauges in or around the watershed were completed. The power form was then applied for fitting as follows:

$$\gamma_d^*\left(h_{ij}, a\right) = \omega_0 h^a = 0.093 h^{0.243},\ \mathrm{R}^2 = 0.906 \qquad (20)$$

where ω_0 denotes the scaled parameter of the scaled climatological mean semivariogram (mm^2). Variance $s^2(t)$ of a realization $\pi(t)$ for each time period t can be easily calculated from the hourly rainfall measurements. Hourly semivariograms of rainfall events can then be directly calculated using equations 1 and 20.

The estimated area must be divided into M grids before calculating the hourly mean rainfall during storm events over the watershed by applying equation 8. The estimated area was divided into $2665 \times 1\text{-}\mathrm{km}^2$ grids. This study used observations from three raingauges located in the Wu-Tu watershed to estimate the hourly mean rainfall for applying to the calibrated and verified events.

The simulated runoff components were exported from the model system. In the processes of translating the rainfall runoff, the model parameters for each event were determined by using the shuffled complex evolution (SCE) optimal algorithm (Duan et al., 1993). These calibrated parameters reflect the complex rainfall-runoff processes resulting from the watershed and meteorological characteristics of each case at that time. They also reflect errors in the rainfall estimates, initial conditions and observed flow. Table 1 shows the comparisons of the simulated and observed runoff hydrographs using the three criteria (CE, EQ_p, and ET_p).

Table 1: Calibration results for the model of three serial reservoirs with one parallel reservoir.

Event names (times)	*CE*	EQ_p (%)	ET_p (hrs)	Shape
CORA (1966-09-06)	0.95	15.47	0	S
BETTY (1972-08-16)	0.97	-0.88	-1	S
BILLIE (1976-08-09)	0.98	-9.01	1	S
VERA (1977-07-31)	0.81	33.86	0	S
ORA (1978-10-12)	0.79	23.08	-2	M
IRVING (1979-08-14)	0.94	18.97	0	S
Storm (1980-11-19)	0.87	18.61	0	S
ANDY (1982-07-29)	0.77	15.90	0	S
CECIL (1982-08-09)	0.80	17.71	0	M
Storm (1983-10-12)	0.96	7.54	1	S
Storm (1983-10-14)	0.99	-5.74	0	S
Storm (1984-06-02)	0.94	-29.21	0	S
Storm (1984-11-18)	0.85	13.01	2	S
NELSON (1985-08-22)	0.91	-2.56	0	S
ALEX (1987-07-27)	0.88	-5.92	2	S
ABE (1990-08-30)	0.76	11.36	-1	S
Storm (1990-09-01)	0.92	-4.66	0	S
Storm (1990-09-02)	0.92	-16.23	2	S
Storm (1994-06-18)	0.85	-16.67	0	S
FRED (1994-08-20)	0.93	15.31	2	S
GLADYS (1994-09-01)	0.91	-17.05	2	S
HERB (1996-07-31)	0.95	6.23	1	S
WINNIE (1997-08-17)	0.79	-2.12	0	S
AMBER (1997-08-29)	0.75	26.26	1	S
Storm (1999-09-26)	0.82	-11.56	4	S
BEBINCA (2000-11-08)	0.68	12.79	0	M
RANANIM (2004-08-12)	0.61	-8.16	1	M
Storm (2004-08-17)	0.87	-13.36	2	S
Storm (2004-10-01)	0.79	12.78	2	S
Storm (2005-05-09)	0.78	26.76	1	S
Storm (2005-09-10)	0.76	-4.62	3	S
Storm (2005-12-04)	0.88	1.44	3	S
Storm (2005-12-11)	0.70	17.90	5	S
Storm (2006-06-06)	0.85	10.57	4	M
Storm (2007-06-15)	0.94	-28.79	1	S
Storm (2007-09-04)	0.94	-18.36	1	S
Storm (2008-05-30)	0.72	-13.62	1	S
Storm (2008-10-10)	0.87	8.55	1	S
Mean	0.85	2.78	1.03	

* The S notation represents a single-peak rainfall event, and the M notation represents a multi-peak rainfall event.

Regarding *CE* for model calibration, 25 calibrated events exceed 0.8, 11 cases are within the intervals of 0.7-0.8, and only one is below 0.7 (Table 1). With regard to

EQ_p, all samples are smaller than 20% except for six typhoons/storms. The ET_p values are all less than or equal to 3 hours; three are longer than 3 hours. The average values of the three criteria CE, EQ_p and ET_p are 0.85, 2.78% and 1.03 hours, respectively. This comparison also exhibits that the calibration is satisfactory for regenerating rainfall-runoff processes. Model calibration using the three evaluation criteria demonstrates that the calibrated parameters are able to illustrate the situation of the studied watershed during rainfall-runoff processes.

6.2 Simulations of hydrograph components

In this study for hydrological modelling, four hydrograph components are defined, but five components are necessary to be determined. Those components are surface runoff, rapid subsurface runoff, delayed subsurface runoff, groundwater runoff and baseflow, respectively. The surface runoff, rapid subsurface runoff, delayed subsurface runoff and groundwater runoff are produced from a rainfall event and they are called “new discharge”. The baseflow is a groundwater flow before rainfall starts and then the lowest discharge of a rising limb in a total flow hydrograph if it is considered as a constant. Therefore, baseflow can be called “old discharge” and is not a newly-generated flow in a rainfall-runoff event.

The model parameters were determined from rainfall and runoff data by applying the structure of the proposed model and its exponential derivations. In reality, various components of excessive streamflow yield from a typhoon event are hard to be correctly measured and divided. An alternative solution was applied herein to generate hydrograph components by using the proposed model. Horizontal outflows of the three linear serial reservoirs with a reservoir in parallel, which simulate surface runoffs, rapid and delayed subsurface runoffs, and groundwater runoff, were obtained based on the calibrated parameters. Figure 3 plots the hydrographs of the quick and slow runoffs for two sets of simulation results in 38 calibrated rainfall-runoff events.

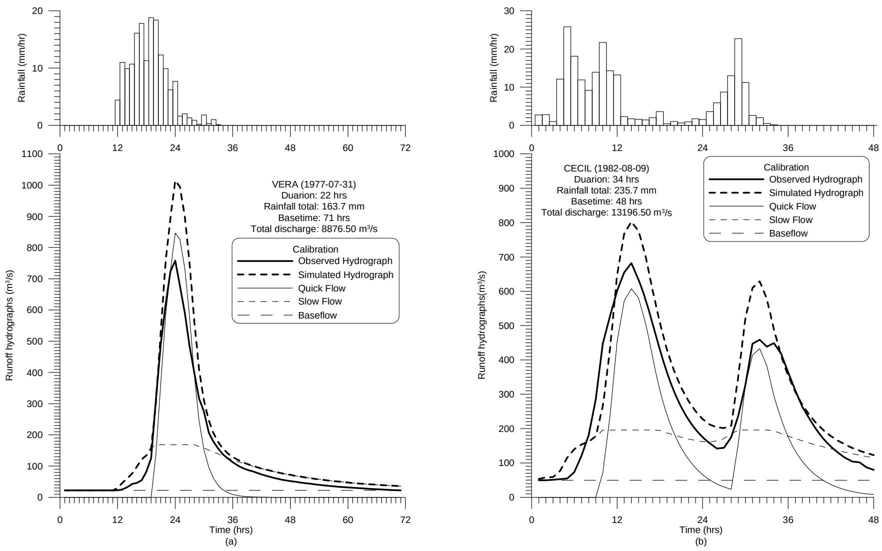

Figure 3: Calibrations of runoff hydrographs for rainfall-runoff events

6.3 Times to peak of hydrograph components

Clarifying times to peak of runoff components is vital to determine the time required to produce maximum discharge of a runoff hydrograph. Thus, this study first addresses the characteristic for time to peak. An attempt is made to identify the relationships between peak time of rainfall and time to peak of runoff components. Figures 4a and b plot the correlations between peak times of hyetographs and both hydrograph components, respectively. These positive correlations, excluding multi-peak rainfall-runoff events, are between peak rainfall for slow runoffs and peak rainfall for quick runoffs. These figures also reveals that the power relationship for peak time between rainfall and quick runoff ($R^2 = 0.63$) is more obvious than between rainfall and slow runoff ($R^2 = 0.47$). The established relationship of rainfall to quick runoff is markedly higher than that of rainfall to slow runoff. This is because slow water flowing beneath land surface is influenced not only by infiltration resulting from rainfall, but also by porosity, soil moisture and hydraulic conductivity of the soil layers. The above analytical results demonstrate that time to peak of a quick flow is highly correlated with peak time of a hyetograph and a slow flow has also a visual correlation with rainfall.

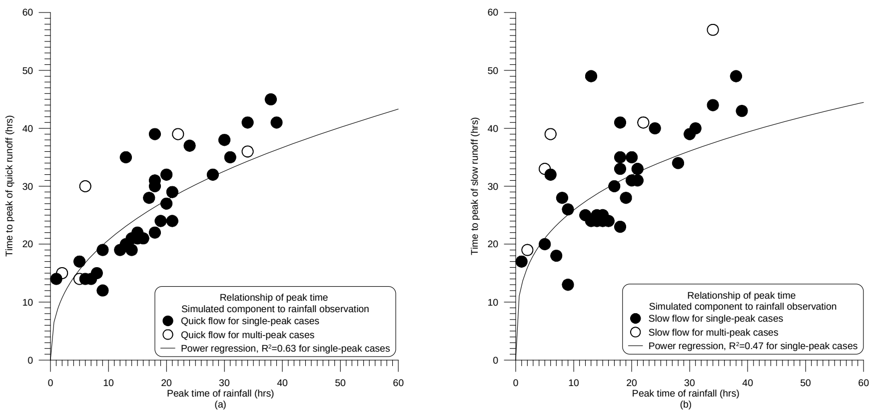

Figure 4: The relationships of peak times between simulated hydrograph components and rainfall observation

Based on the above results, this study concludes that time to peak of a slow runoff is later than that of a quick runoff. Moreover, the times to peak of both component hydrographs are related to peak time of rainfall, and their relationships are power form excluding for the multi-peak events.

6.4 Peak discharges of hydrograph components

The characteristic of the peak discharge of a hydrograph is essential for designing hydraulic structures. Hence, this study also analyzes the relationships between hydrograph components and observed total runoffs in terms of peak discharges. The above analytical findings indicate that a large total runoff hydrograph (a sum of quick, slow runoffs and baseflow) has a large peak for quick runoff, and is larger than that of a slow runoff.

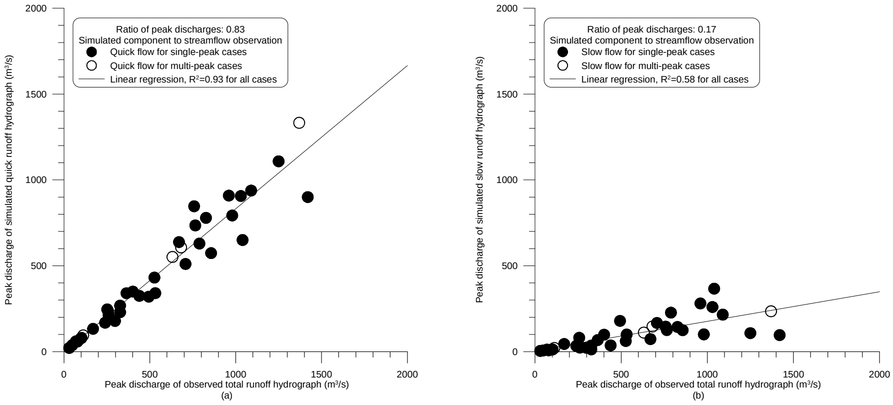

Figure 5: The relationships of peak discharges between simulated hydrograph components and observed total runoffs.

Figure 5 plots the obvious relationships for peak discharges between component hydrographs and observations of total runoffs. Two linear relationships are evident according to R^2 values, i.e. $R^2 = 0.93$ and $R^2 = 0.58$ for simulated quick and slow runoffs to total runoff observations, respectively. The extent of correlation for quick runoff with total runoff is stronger than that of slow runoff with total runoff because slow runoff movements in an aquifer are more complex than surface runoff (quick runoff) that runs on the ground surface. Figure 5 further indicates that, while peak discharges of quick runoffs are slightly smaller than those of observed total runoff, peaks of slow runoffs are significantly smaller than those of observed total runoffs. With respect to multi-peak and single-peak cases, the ratios are 1-0.83 for observed total runoffs to surface (quick) runoffs and 1-0.17 for observed total runoffs to slow runoffs.

6.5 Total discharges of hydrograph components

Finally, this study discusses the final characteristic of hydrograph components. Theoretically, a surface (quick) runoff discharge should be larger than a slow runoff discharge during a rainfall-runoff episode.

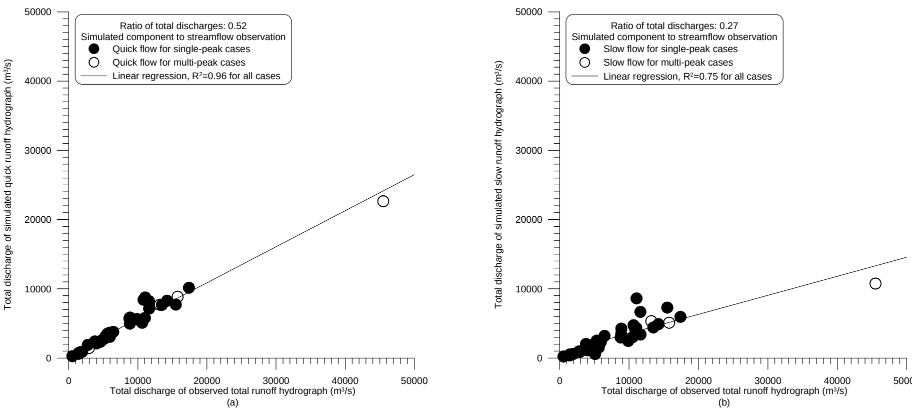

Figure 6: The relationships of total discharges between simulated hydrograph components and observed total runoffs.

Figure 6 plots the comparison results of individual components to observed total runoff for further identifying the ratio percentages of component flows during rainfall-runoff episodes. For the same events, the points representing specific values for total discharges of surface (quick) runoffs to those of total runoffs (Figure 6a) are above those resulting from ratios of slow runoffs to total runoffs (Figure 6b). According to Figures 6a and b, volume of quick flows is larger than that of slow flows in rainfall-runoff generations. Both variations of roughly straight lines can be found for percentages of quick flows to total flows ($R^2 = 0.96$) and slow flows to total flows ($R^2 = 0.75$). Regardless of multi-peak or single-peak rainfall-runoff events, the volume of a surface runoff is 52% volume of the total runoff and 27% for that of a slow runoff; whereas the remainder is baseflow components.

7. CONCLUSIONS

This study used a model of three serial reservoirs with one parallel reservoir and limited seven significant parameters to simulate runoff components in a river outlet. The use of the block Kriging method can help to acquire the best parameters to represent the hydrological and geomorphic conditions. Based on the analytical results of the calibrations, the parameters were established and offer effective assistance on observing runoff components in streamflows of a watershed outlet. The regenerated results show this model is suitable to evaluate hydrological conditions in this and other watersheds and to apply it further to watershed management in Taiwan.

The quick and slow runoffs regenerated from the proposed model reveal satisfactory characteristics of runoff components, i.e. hydrographs of quick flows have large peak discharges, whereas slow flows have small peak discharges. Based on the results of this study, the following significant findings are described:

(1) The times to peak for both hydrograph components of single-peak events is an increasing power correlation corresponding to peak time of a hyetograph. The relationship resulting from quick runoff is markedly stronger than that from slow runoff;

(2) The peak discharges of hydrograph components for all events are directly and linearly proportional to observations of a total runoff. The linear correlation resulting from quick runoffs is higher than that from slow runoffs. The ratio of a quick runoff to the observed total runoff is approximately 83% and 17% for a slow flow to observations of the same total runoff; and

(3) The relationships of total discharges for all events also have direct ratios between hydrograph components and observations of total runoffs; total discharge of a quick runoff component is 52% that of a total runoff and 27% of that for a slow runoff. The remainder is baseflow in the same total flow. When given rainfall conditions and total runoff hydrographs, analytical results of this study significantly contribute to efforts to evaluate hydrograph characteristics of quick and slow runoffs and, thus provide a valuable reference for watershed management in Taiwan.

REFERENCES

Agirre, U., Goñi, M., López, J. J., and Gimena, F.N., 2005. Application of a unit hydrograph based on subwatershed division and comparison with Nash's instantaneous unit hydrograph. *Catena* 64, 321-332.

Ahmad, M. M., Ghumman, A. R., and Ahmad, S., 2009. Estimation of Clark's instantaneous unit hydrograph parameters and development of direct surface runoff hydrograph. *Water Resources Management* 23, 2417-2435.

Bastin, G., Lorent, B., Duque, C., and Gevers, M., 1984. Optimal estimation of the average rainfall and optimal selection of raingauge locations. *Water Resources Research* 20, 463-470.

Bhadra, A., Bandyopadhyay, A., Singh, R., and Raghuwanshi, N. S., 2010. Rainfall-Runoff Modeling: Comparison of Two Approaches with Different Data Requirements. *Water Resources Management* 24, 37-62.

Chen, R. S., Pi, L. C., and Huang, Y. H., 2003. Analysis of rainfall-runoff relation in paddy fields by diffusive tank model. *Hydrological Processes* 17, 2541-2553.

Cheng, S. J., and Wang, R. Y., 2002. An approach for evaluating the hydrological effects of urbanization and its application. *Hydrological Processes* 16, 1403-1418.

Cheng, S. J., Hsieh, H. H., and Wang, Y. M., 2007. Geostatistical interpolation of space-time rainfall on Tamshui River Basin, Taiwan. *Hydrological Processes* 21, 3136-3145.

Cheng, S. J., Hsieh, H. H., Lee, C. F., and Wang, Y. M., 2008b. The storage potential of different surface coverings for various scale storms on Wu-Tu watershed, Taiwan. *Natural Hazards* 44, 129-146.

Cheng, S. J., Lee, C. F., and Lee, J. H., 2010. Effects of Urbanization Factors on Model Parameters. *Water Resources Management* 24,775-794.

Clarke, R. T., 1973. A review of some mathematical models used in hydrology, with observations on their calibration and use. *Journal of Hydrology* 19, 1-20.

Duan, Q., Gupta, V. K., and Sorooshian, S., 1993. Shuffled complex evolution approach for effective and efficient global minimization. *Journal of Optimization Theory Application* 76, 501-521.

Franchini, M., and O'Connell, P. E., 1996. An analysis of the dynamic component of the geomorphologic instantaneous unit hydrograph. *Journal of Hydrology* 175, 407-428.

Hashino, M., Yao, H., and Yoshida, H., 2002. Studies and evaluations on interception processes during rainfall based on a tank model. *Journal of Hydrology* 255, 1-11.

Hsieh, L. S., and Wang, R. Y., 1999. A semi-distributed parallel-type linear reservoir rainfall-runoff model and its application in Taiwan. *Hydrological Processes* 13, 1247-1268.

Huang, H. J., Cheng, S. J., Wen, J. C., and Lee, J. H., 2008a. Effect of growing watershed imperviousness on hydrograph parameters and peak discharge. *Hydrological Processes* 22, 2075-2085.

Huang, S. Y., Cheng, S. J., Wen, J. C., and Lee, J. H., 2008b. Identifying peak-imperviousness-recurrence relationships on a growing-impervious watershed, Taiwan. *Journal of Hydrology* 362, 320-336.

Jakeman, A. J., Littlewood, I. G., and Whitehead, P. G., 1990. Computation of the instantaneous unit hydrograph and identifiable component flows with application to two upland catchments. *Journal of Hydrology* 117, 275-300.

Jakeman, A. J., and Hornberger, G. M., 1993. How much complexity is warranted in a rainfall-runoff model? *Water Resources Research* 29, 2637-2649.

Jin, C. X., 1992. A deterministic gamma-type geomorphologic instantaneous unit hydrograph based on path types. *Water Resources Research* 28, 479-486.

Kliment, Z., and Matoušková, M., 2009. Runoff changes in the Šumava Mountains (Black Forest) and the Foothill Regions: extent of influence by human impact and climate Change. *Water Resources Management* 23, 1813-1834.

Lee, Y. H., and Singh, V. P., 2005. Tank model for sediment yield. *Water Resources Management* 19, 349-362.

Madsen, H., 2000. Automatic calibration of a conceptual rainfall–runoff model using multiple objectives. *Journal of Hydrology* 235, 276-288.

Mays, L. W., and Taur, C. K., 1982. Unit hydrographs via nonlinear programming. *Water Resources Research* 18, 744-752.

Melone, F., Corradini, C., and Singh, V. P., 1998. Simulation of the direct runoff hydrograph at basin outlet. *Hydrological Processes* 12, 769-779.

Nash, J. E., 1957. The form of the instantaneous unit hydrograph. *IAHS Publications* 45, 112-121.

Nourani, V., Singh, V. P., and Delafrouz, H., 2009. Three geomorphological rainfall-runoff models based on the linear reservoir concept. *Catena* 76, 206-214.

O’Connell, P. E., and Todini, E., 1996. Modelling of rainfall, flow and mass transport in hydrological systems: an overview. *Journal of Hydrology* 175, 3-16.

Sugawara, M., 1979. Automatic calibration of the tank model. *Hydrological Science Bulletin* 24, 375-388.

Sugawara, M., 1995. ‘Tank model’, in Singh, V. P. (ed.), Computer Models of Watershed Hydrology, *Water Resources Publications*, Littleton, Colorado.

Yue, S., and Hashino, M., 2000. Unit hydrographs to model quick and slow runoff components of streamflow. *Journal of Hydrology* 227, 195-206.

A Study on the Planning Regulations of Shin-Hu-Wei Creek Basin, Taiwan

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ABSTRACT

Yuan-Chang and Tuku Townships, center of the land subsidence area of Yunlin County in Taiwan, belongs to Shin-Hu-Wei Creek Drainage System. Highly potential occurrences of floods exist in these areas because of difficult drainage. To mitigate the inundation problem and protect the resident's life and property, this study develops an appropriate comprehensive flood control solution to reduce flood disasters by considering ecological conservation and environmental landscape. The major inundation areas were evaluated by a topographical survey, hydrological analysis, and hydraulic modeling. Sobek was used as a tool for creating flood simulations. Results show three main flood regions occurred at (1) the estuary of Shin-Hu-Wei Creek from Wen-Kang Bridge to West-Mailiao Tributary surrounding the river catchment area, (2) the downstream area close to the inlet of the Hsin-Zhuang-Zi Tributary, and (3) the section from Pu-Tzu Bridge to Ho-Ping Bridge. The flood control measures and improvement plan include (1) heightening the river dike, (2) widening the entrance of the regional drainage system, and (3) regulating the main channel. Additionally, a retention pond is proposed to be installed at the *upper stream of Ho-Ping Bridge. The benefit-cost ratio is 1.1. The feasibility of the project is positive for flood mitigation and public safety.*

Keywords: *hydrological analysis, hydraulic modeling, flood mitigation*

1. INTRODUCTION

Flowing into the Taiwan Strait, the Shin-Hu-Wei Creek is located between Zhuoshuixi River and the Old Hu-Wei River and passes through Cihtong, Siluo, Erlun, Tuku, Lunbei, Baojhong, Dongshih, Taisi, and Mailiao villages (Figure 1). The total length of this flood control plan is approximately 45 km from the Qiong-Jiao Control Gate to the estuary of the Shin-Hu-Wei Creek. The major watershed area covered by the plan is 107.12 km^2. This study is based on hydrological conditions, land use, drainage characteristics, environmental characteristics, topographical surveys and flooding disasters, and an appropriate comprehensive flood control solution to reduce flood disasters by considering ecological conservation and environmental landscapes. We can propose effective solid solutions and management strategies to the related authorities for future river regulations, management, and environmental developments to be used as a reference.

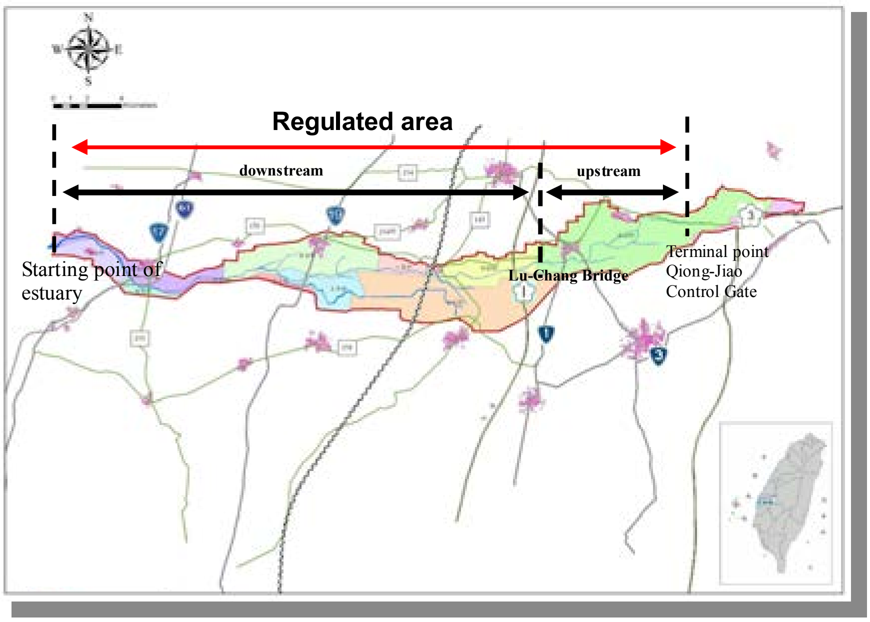


Figure 1: Shin-Hu-Wei Basin Map

2. RESEARCH PROJECT

The content of this project are as follows:
（1）Investigation of basic information
（2）Hydrological analysis
（3）Creek characteristics and hydraulic analysis
（4）Flood control measures and improvement plan
（5）Environmental planning
（6）Engineering solutions and evaluation

3. RESEARCH RESULTS

3.1 Investigation of basic information

After the investigation, the basic information of the Shin-Hu-Wei catchment is summarized as follows:

（1）The average temperature is around 23 degrees Celsius, the average annual rainfall of about 1,400 mm, and the relative humidity of about 82.5 percent.

（2）The territorial regions of this river were divided into specialized agricultural areas of about 57.64% followed by generalized agricultural areas in the proximity of 12.62%. In addition, the remaining classifications were industrial zones, urban planning districts, specialized areas, and rural areas.

（3）The Water Conservancy Bureau is responsible for operating the irrigation of farmland. There are three major water outtakes from upstream to downstream: the You-Che discharge channel, the first discharge channel, and the second discharge channel. There are two water intakes which deliver water to the surrounding irrigation area: a branch of Shin-Hu-Wei and the already existing Lu-Chang Ke channel.

（4）Three villages, Chitong, Lunbei, and Mailiao, had constructed stormwater sewer systems. The stormwater sewer systems were planned by the Bureau of Residential and Urban Development and were finished in 1976 and 1982.

（5）Twenty four kinds of birds, three kinds of fish, eight kinds of mammals, and five kinds of reptiles were found in the Shin-Hu-Wei catchment.

（6）The water quality according to the monitoring stations for pollution indicators generally showed moderate pollution. The reason is that the main water source of the Shin-Hu-Wei comes from the interflow of Chou-Shui River which contains high concentrations of suspended solids.

3.2 Hydrological analysis

The hydrological analysis of the Shin-Hu-Wei was based on historical one-day and two-day rain storm records. Computation of the areal average rainfall was performed by the Thiessen polygon method based on the rainfall records from 1961 to 2006. For the frequency analysis of rainstorms, five theoretical distribution models were used, namely lognormal distribution with two parameters, lognormal distribution with three parameters, Pearson type Ⅲ distribution, Log-Pearson Ⅲ distribution, and extreme value distribution. The Horner rainfall pattern of Hu-Wei station was selected as the design rainfall pattern. Three methods were used to estimate peak flow, which were the rational formula, triangle hydrograph and dimensionless unit hydrograph. The peak flow with a return period of 50 years was used as the design flood flow for making further analysis of the hydraulic model and the use of engineering plans.

3.3 Creek characteristics and hydraulic analysis

(1) Qualitative analysis

A. Slope and pattern

The average decline gradient of the Shin-Hu-Wei is 1/747; generally the creek gradient changes moderately. The main channel gradient ascends progressively. According to the creek characteristics, the creek flow is slow and has little erosion impact on the creekbed.

B. Changes of longitudinal section

The main channel bed generally contains fine particle sizes. The reason is that the creek passes through a non-mountainous valley. Therefore, no supply source of sand and gravel is provided.

C. Comparison of river erosion and deposition

From the segment of the new Lu-Chang Bridge to the sea, channel cross-sections were rectified by the Planning and Design Division of the Water Conservancy Bureau in 1986. These channel sections are regulated. However, subsidence has caused the elevation of the main channel to be lower than the mean sea level. In addition, although planning for the upper reaches has been performed by the Yunlin County Government in 1990, the practical engineering projects have not yet been implemented. Therefore, the average height has created no significant changes in the creekbed.

(2) Hydraulic analysis of current status

A. Roughness coefficients

The Shin-Hu-Wei Creek was divided into 189 sections. The roughness coefficients for these sections of the Shin-Hu-Wei were referred to according to the planning reports of 1986 and 1990 and the manual of river management and environmental planning. The roughness coefficients used for Sections 1 to 29 was 0.028; from Sections 30 to 140 was 0.03, and from 140.2 to 189 was 0.015.

B. Start water level

In this study the start water level 3.32 m was used as a basis for creating further simulations.

C. Flood capacity evaluation

Besides Po-Tzu Bridge and Ho-Ping Bridge, the existing dikes were mostly capable of withstanding a 50-year flood return period (Figure 2).

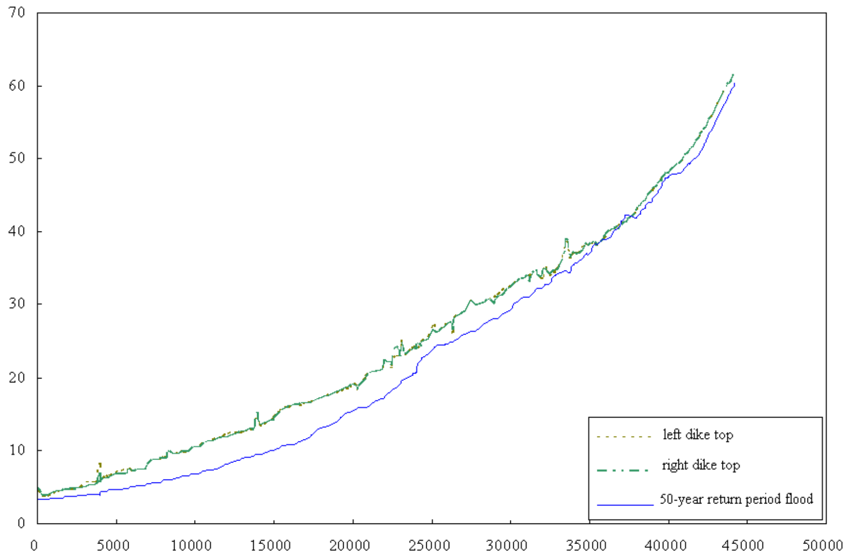


Figure 2: River Profile Diagram

D. Safety evaluation for cross-river structures

There are totally 56 cross-river structures on the Shin-Hu-Wei Creek from the Lu-Chang Bridge to the estuary of the Shin-Hu-Wei. According to the hydraulic analysis based on the peak flow of a 50-year return period with a freeboard margin of 1.5 meters, safety for most of the cross-river structures are bearable except for the Xin-Zhuang Bridge. Suggestions have been made to raise the bridge abutments of the upstream bridges from the Lu-Chang Bridge to the Qiong-Jiao Controlling Gate; the flow section is insufficient owing to the depth of the main beam which obstructs the flow from passing through.

E. Inundation simulation and analysis

The SOBEK model was used which combines the function of a one-dimensional channel flow and a two-dimensional overland flow to analyze the flood potential of the Shin-Hu-Wei Creek basin in Taiwan. The river watershed conceptual model was created by overlapping a 1/5000 site surveyed topographic map onto the digital terrain model (DTM) prepared by the Ministry of the Interior. Simulations based on design storms of different return periods were then carried out. Results show that the flood zones in the catchment occurred at three major locations (Figure 3): from the estuary of Shin-Hu-Wei Creek to the West-Mailiao Tributary surrounding the river catchment area, the confluence of the Shin-Hu-Wei Creek, and the Hsin-Zhuang-Zi Tributary, and the area from the cross-section of Pu-Tzu Bridge to the cross-section of Ho-Ping Bridge.

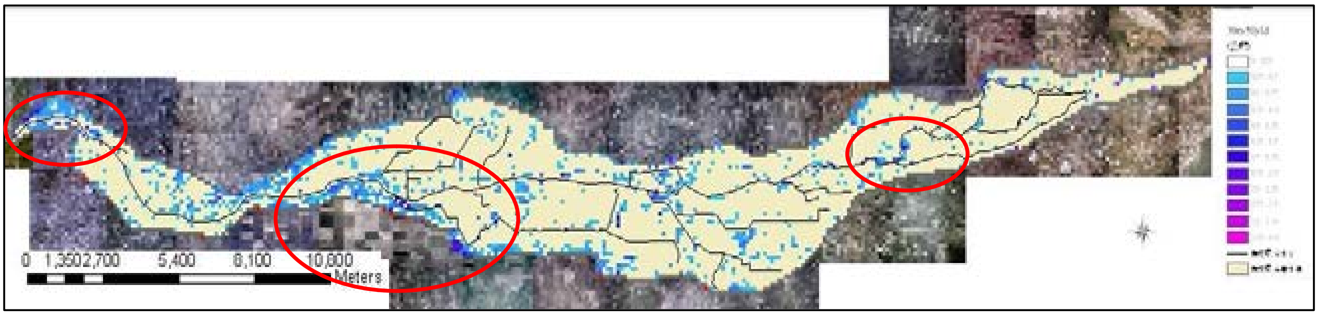


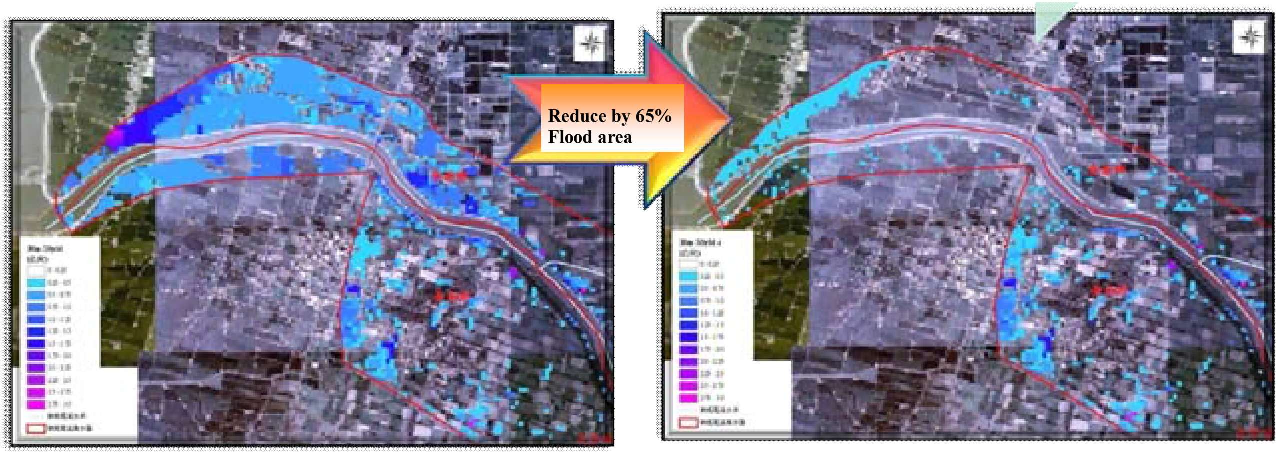
Figure 3: Major flooding regions in catchment area

3.4 Flood control measures and improvement plan

An appropriate comprehensive flood control program for inundation zones were designed according to the local conditions and overall consideration of the river catchment, which is primarily for reducing flood disasters and secondarily for improving ecological conservation and the environmental landscape. Three solutions were proposed according to the inundation simulation and analysis:

(1) Downstream (Wen-Kang Bridge) 0 k + 239 ~ 2 k + 698

Simulation results show that the dike heights in most sections are sufficient to handle flooding except for the area from the cross-section of Wen-Kang Bridge to the estuary of the Shin-Hu-Wei Creek. The reason is because of the serious subsidence along the coastal area. There is about 20 ~ 90 cm shortage of height regarding the embankment. Suggestions were proposed to prevent overflow and reduce damages by heightening the river dikes, and by pumping in advance about 30~90 cm of water in depth from the fish ponds before a torrential rain comes (Figure 4).



The status of flood situation Improved flood situation

Figure 4: The improved results of downstream (Wen-Kang Bridge)

(2) The confluence of the Shin-Hu-Wei Creek and the Hsin-Zhuang-Zi Tributary

The original gate size was enlarged to 6 m * 2 m instead of 6 m * 1.5 m. Therefore, the water trapped at the confluence of the Shin-Hu-Wei and the Hsin-Zhuang-Zi Tributary was avoided (Figure 5).

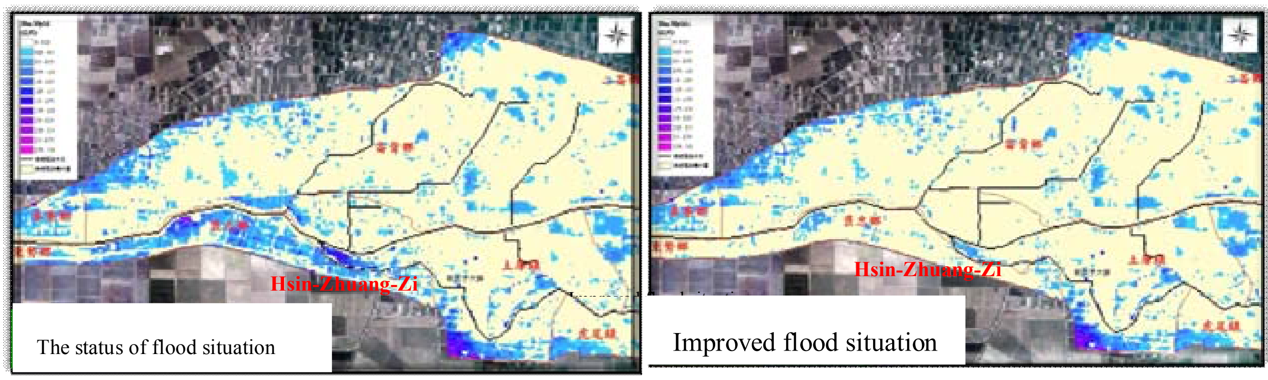


Figure 5: The improved results of downstream area close to the inlet of the Hsin-Zhuang-Zi Tributary

(3) The area from the cross-section of Pu-Tzu Bridge to the cross-section of Ho-Ping Bridge

A suggestion to install a detention pond with a capacity of 370,800 cubic meters was proposed. The detention pond will be about 15.14 hectares with a 3.5 meter depth and 1:3 gentle slope, which may reduce flooding in 103 hectares of the flood area (Figure 6).

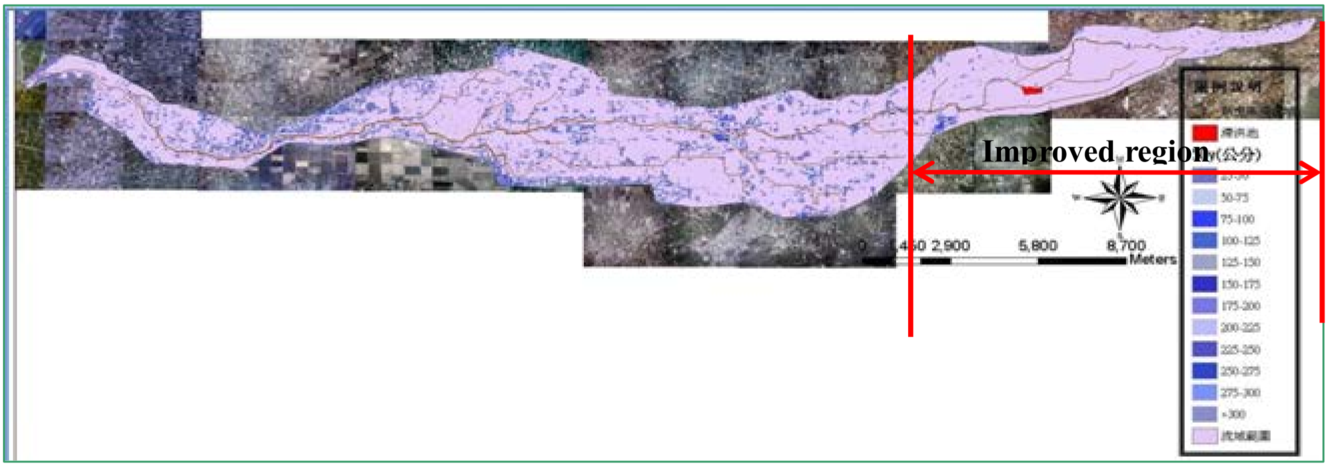


Figure 6: The improved results of the section from Pu-Tzu Bridge to Ho-Ping Bridge

3.5 Environmental planning

Environmental planning within the region needs to take into account the irrigation drainage, ecological protection, recreational functions, and so on throughout the planning process to develop a sustainable environment for Shin-Hu-Wei Creek. Based on environmental characteristics of the river as well as the local geographical and cultural characteristics of the river environment for effective management, the plan proposes to divide the Shin-Hu-Wei Creek basin into eight regional segments according to their environmental characteristics. In the future, these segments will be adjusted according to their socio-economic development, the characteristics of their local disasters, and the local residents' opinions.

4. CONCLUSION

The planned engineering solutions include heightening the river dike (from 0 k + 239 to 2 k + 689), widening the entrance of the regional drainage system, and regulating the main channel. Additionally, a detention pond is under consideration to be installed upstream of Ho-Ping Bridge at the 34 k + 900 to 38 k + 220 river distance. Functions of the detention pond are to attenuate the peak flow and retard the time of peak flow.

REFERENCES

Water Resources Planning Institute, Water Resource Agency, 2006. *The Planning of Regulation of River Management and Environment*, Taiwan.

Water Resources Planning Institute, Water Resource Agency, 2006. *The Planning of Regulation of Southern Yunlin Coast*, Taiwan.

Water Resources Agency, Regulation Project of Flood-prone Areas
(Website: http://fcp.wra.gov.tw/default.asp?mp=11)

Developing Technology for Multiple-Hazards Protection

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ABSTRACT

This paper outlines the development of the Protective Technology Research Centre (PTRC) at Nanyang Technological University (NTU). The paper also describes PTRC's core R&D capabilities, which have over time evolved into the foundation of technologies that can be employed for protection against multiple hazards. The multiple hazards described here include the effects of natural forces such as earthquakes as well as those of manmade ones from underground explosion or surface explosion events which may be related to homeland security.

Keywords: *multiple-hazards protection, earthquakes, explosions, homeland security*

1. INTRODUCTION

The Protective Technology Research Centre (PTRC) is an inter-disciplinary research centre, established on 29 September 1998 via a Memorandum of Understanding (MOU) signed between the Ministry of Defence (MINDEF) and the Nanyang Technological University (NTU) in Singapore. PTRC is hosted in the School of Civil and Environmental Engineering (CEE) at NTU, and is primarily funded by NTU and MINDEF. On 9 September 2008, NTU and MINDEF signed its second renewal of MOU for PTRC via the Defence Science and Technology Agency (DSTA) for another 5 years.

The Centre provides a platform for synergistic R&D programmes which involve NTU's schools in science and engineering colleges. The three-fold mission of PTRC is:

- To spearhead research efforts in developing advanced protective technology and homeland security
- To provide professional education/training and technology transfer
- To provide specialised advisory services to government ministries and local industry

Most of the joint R&D projects in PTRC have been supported by DSTA, MINDEF. PTRC's R&D project with DSTA on the development of underground space for civilian and military uses represents one of the most successful examples of joint R&D projects with the industry or government agencies. The project supports the national effort in constructing caverns and tunnels within granite, as well as sedimentary rocks for the storage of strategic materials.

As part of the Underground Technology and Rock Engineering (UTRE) programme, DSTA and PTRC, together with geologists of Building and Construction Authority (BCA), studied soil samples over the past 2 years to compile the *Geology of Singapore*. The second edition of *Geology of Singapore* was launched in 2009 at the Inaugural Defence Construction Seminar. It will be a useful reference for construction and urban planning professionals, who are constantly looking for space to develop in the land-scarce Singapore.

The *Straits Times* article on the Construction of Jurong Rock Cavern (dated 16 April 2009) shows the successful transfer of PTRC technology which had started for military usage with DSTA has transformed itself successfully to civilian usage, in which PTRC and DSTA act as consultants to JTC Corp. The Jurong Rock Cavern, which is an excellent example of dual-use technology applicable to both military and civilian domains, will be the first underground oil storage facility in Singapore and Southeast Asia.

2. PTRC CORE R&D CAPABILITIES

PTRC has carried out many joint R&D projects with various agencies. Some of the projects have been on the effects of dynamic, explosion or blast loading on blast doors, foundations of civil defence shelters, underground facilities and aboveground structures. These research projects involve both numerical simulations and experimental investigations on the effects of high-intensity transient dynamic loading on soil and rock media, as well as on structural components and structural systems. The core R&D capabilities of PTRC can thus be broadly grouped into three areas as follows:-

- Soil and Rock Dynamics
  - Underground cavern development
  - Tropical soil engineering

- Structural Dynamics
  - Structural damage under ground shocks
  - Blast and fire response of building components and systems

- Computational Mechanics
  - Constitutive models for concrete perforation and break-up
  - Dynamic properties of rock materials

3. LEADERSHIP IN PROTECTIVE TECHNOLOGY DEVELOPMENT AND PTRC CONTRIBUTION TO DEFENCE

PTRC's growth and development over the last 12 years has spearheaded the following major R&D projects which have made significant impact on advancing protective technology in Singapore's defence capabilities:

3.1 Underground Technology & Rock Engineering (UTRE) R&D Programme and Underground Ammunition Facilities (UAF) Project

PTRC has provided the effective management and crucial leadership for the success of initial R&D projects on *Rock Cavern Engineering* and *Ground Shock Effects on Buildings*. These two projects provided the direct technical support and input to the engineering and construction of UAF inside granite formation. The outstanding outcomes of these two initial R&D projects of PTRC did not only lead to the establishment of a long-term R&D programme in *Underground Technology & Rock Engineering* (UTRE), but also the winning of an Outstanding Engineering Achievement Award by the Institution of Engineers Singapore (IES), besides upgrading the North Atlantic Treaty Organisation (NATO) codes to enhance the safety of underground ammunition storages as well as to reduce the inhabited building distance (IBD) for surface structures.

What is even more worth noting is the extension of technologies resulting from the UTRE R&D programme to the engineering and construction of Jurong Rock Cavern (JRC). The success of extending UTRE R&D results for UAF to the JRC construction, the first in Southeast Asia for petroleum storage underground, demonstrates the combined capability of PTRC & DSTA in developing dual-use technology which can be used for both defence and civilian applications.

3.2 Concrete Penetration and Breakup Simulation R&D Projects

PTRC has worked with Swedish defence research organisation in starting an R&D project on perforation of concrete targets which involved both numerical simulations and experimental validations. Resulting from these initial investigations, a multi-surface stress-state model, which is a dynamic plastic damage material model developed to simulate the response of concrete targets. When compared with experimental data, the model simulated very well the perforation of a rigid steel projectile through concrete panels at 30 degrees obliquity.

This model has attracted much interest from the Klauz group for further work. It was thus further developed in a subsequent project to simulate the structural breakup modeling of both uncovered and earth-covered reinforced concrete magazines under internal high loading-density detonation up to 30 kg/m^3. This was complemented with an in-house program developed to determine the debris dispersion patterns and the hazard zone.

4. PIONEERING R&D WORK IN BUILDING SECURITY FOR HOMEFRONT SECURITY

Before the 911 incidents in the USA, PTRC had pioneered the R&D work together with DSTA in understanding the progressive collapse of non-hardened building structures. The R&D work was then quickly evolved into a core project with Ministry of Home Affairs, Homefront Security Division (HSD), to investigate the blast performances of high-rise commercial buildings, government buildings, and high-risk private buildings. This set of extensive initial R&D work forms the basis of the subsequent development at PTRC in Building Protection for homefront security.

4.1 Leadership in Building Security Research

In carrying out the above R&D work before and after the 911 incidents in the USA, PTRC has demonstrated the vision and leadership in providing technologies to support the homefront security needs. This close collaboration with MHA HSD on the disproportional collapse of buildings has resulted in the production of MHA's book of guidelines for the building industry on building security in Singapore. The success of PTRC's pioneering efforts in this domain is clearly reflected by the recent signing of MOU between NTU and MHA to collaborate via PTRC with NTU for the Building Security Research Programme which focuses not only on R&D in progressive collapse of building structures, but also on education and ad-hoc consultancy services.

5. INNOVATIVE CONTRIBUTIONS TO NATIONAL SECURITY VIA EARTHQUAKE ENGINEERING

5.1 Pioneer Earthquake Engineering work for Singapore and the Region via Sumatra Studies

PTRC has pioneered NTU's R&D work on several aspects of earthquake threat to Singapore's built environment, starting from the earthquake source to the building performance. On earthquake source, PTRC has investigated the potential devastating earthquakes in Sumatra that could occur in the future. The research team has derived a set of attenuation relationships to predict the rates of decay of seismic waves travelling from the source to Singapore. In addition, PTRC has also started the investigation of response of soft soil site which is a critical aspect of ground motion intensity in Singapore as demonstrated by the past experience of building responses to Sumatra tremors.

PTRC has also pioneered a research programme on real-time building response measurement system to better understand the effects of the Sumatra tremors on Singapore's high-rise buildings. This research programme is now supported by both Ministry of Home Affairs (via HSD) and Ministry of National Development (via BCA and Housing Development Board) to establish a National Data Centre of Seismic Building Response. It started with instrumentation of 81 residential and commercial buildings in Singapore, which provide the real-time response data for analysis and display of results on a geographical information system (GIS) platform that can be shared among several government agencies to decide on the necessary post-tremor actions.

With PTRC's national leadership in understanding the effects of Sumatra tremors on Singapore buildings, it now leads a national committee which is looking into the establishment of Singapore's earthquake loading requirements as part of building code upgrading. In the international arena, PTRC provides the leadership of Southeast Asia region via Prof Pan's role on the Governing Board of Global Earthquake Model (GEM) Foundation of Organisation for Economic Co-operation and Development (OECD). PTRC's leadership is demonstrated in the recent call of a GEM-SEAsia Regional Workshop at NTU which attracted the attendance of senior researchers and government agencies from around ASEAN, plus Australia and New Zealand.

Development of simulation exercise for emergency response headquarters focused on management by objectives

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ABSTRACT

Disaster Reduction and Human Renovation Institution (DRI) developed a simulation exercise for emergency response headquarters, management by objectives (SEMO), based on the result of several years of experience. The purpose of SEMO is to perform and learn how to manage an emergency response headquarters based on management by objectives. Participants of SEMO follow the whole situation of the crisis event from fragmented information, develop an action plan based on the strong objectives of the organization, and conduct strategic public relations to realize objectives. Management by objectives is one type of management thinking. The authors adapt this thinking to the style of disaster response as an organization based on disaster occurrences. Management by objectives consists of three principles: sharing the common operational picture with all concerned, developing action plan with strong objectives, and conducting strategic public relations. The basic model of SEMO consists of five stages; orientation, team meeting, exercise, simulated press conference, and evaluation. Exercise means the field participants practice management of emergency response headquarters according to management by objectives. To design a real exercise, the basic model is customized based on constrained conditions, characteristics of participants, the object of exercise, and time for exercise. In this case, a training course based on SEMO is conducted at DRI. As a result, participant satisfaction is improved, and participants can understand management by objectives. SEMO is an effective exercise for emergency response officials to learn how to manage an emergency response headquarters.

Keywords: simulation exercise, management by objectives, public relations, common operational picture, incident action plan

1. INTRODUCTION

Disaster Reduction and Human Renovation Institution (DRI) developed a simulation exercise for emergency response headquarters, management by objectives (SEMO), based on the result of several years experience (Kondo, 2009).

The purpose of SEMO is to perform and learn how to manage an emergency response headquarters based on management by objectives. Participants of SEMO follow the whole situation of the crisis event from fragmented information, develop an action plan based on the strong objectives of the organization, and conduct strategic public relations to realize objectives.

Management by objectives is one type of management thinking. The authors adapted this thinking to the style of disaster response as an organization based on disaster occurrences such as the Mid-Niigata Prefecture Earthquake (Kondo, 2006) and Hurricane Katrina (Kondo, 2007). Management by objectives consists of three principles: “sharing the common operational picture with all concerned”, “developing action plan with strong objectives”, and “conducting strategic public relations”.

The basic model of SEMO consists of five stages (Figure 1): “operation”, “team meeting”, “exercise”, “simulated press conference”, and “evaluation”. To design a real exercise, the basic model is customized based on constrained conditions, characteristics of participants, the object of exercise, and time for exercise. “Exercise” means the field participants practice management of emergency response headquarters according to management by objectives.

In this paper, outlines of three principles of management by objectives and an exercise based on SEMO are introduced.

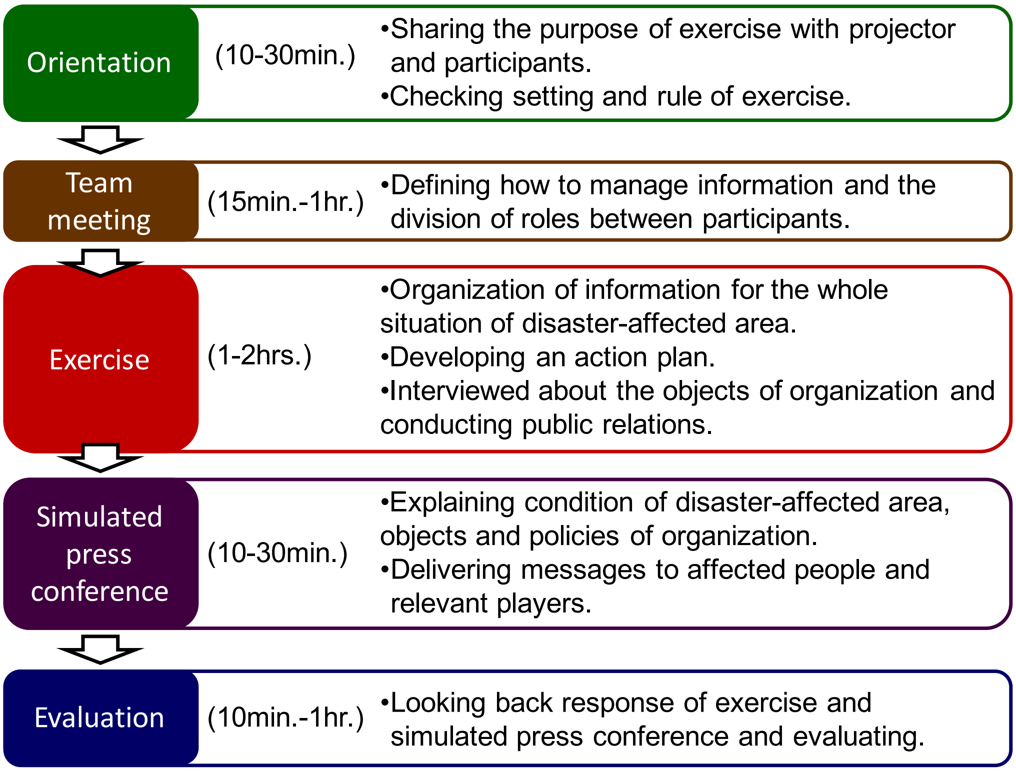

Figure 1: The basic model of SEMO

2. MANAGEMENT BY OBJECTIVES

2.1 Sharing the common operational picture with all concerned

"Information sharing" and "Sharing the common operational picture" are different concepts. "Sharing the common operational picture" is one of the main functions of emergency response headquarters. However, in reality quantified details of disaster affected area are only reported from relevant players. These reports are given to the emergency response headquarters for information sharing, but conditions of the affected area and emergency response information suggestions are more important. Therefore the headquarters should follow the whole situation from fragmented information such as the number of evacuees, staffing in shelters, and the damage level of hospitals.

Figure 2 shows the process for sharing the common operational picture. This process is modeled on disaster response on some local governments in Japan. Headquarters' officers derive internal environment such as "Food and drinking water are stored for only capacity of shelters" and "There is no system to connect shelters with emergency response headquarter", and external environment such as "It is highly possible that some affected people could not live in a shelter" and "It will be high temperature" from the combination of information. Combining internal environment and external environment, "Situation of shelters could not be completely figured out" is recognized by the lack of connection between shelters and emergency response headquarters, and it is easy to estimate that "There are not enough relief supplies at some shelters" because some affected people are not living in shelter and food and drinking water are stored for only the capacity of shelters. Also, because of high temperatures, "Enough drinking water should be obtained" and "There is high risk for food poisoning" become an assignment.

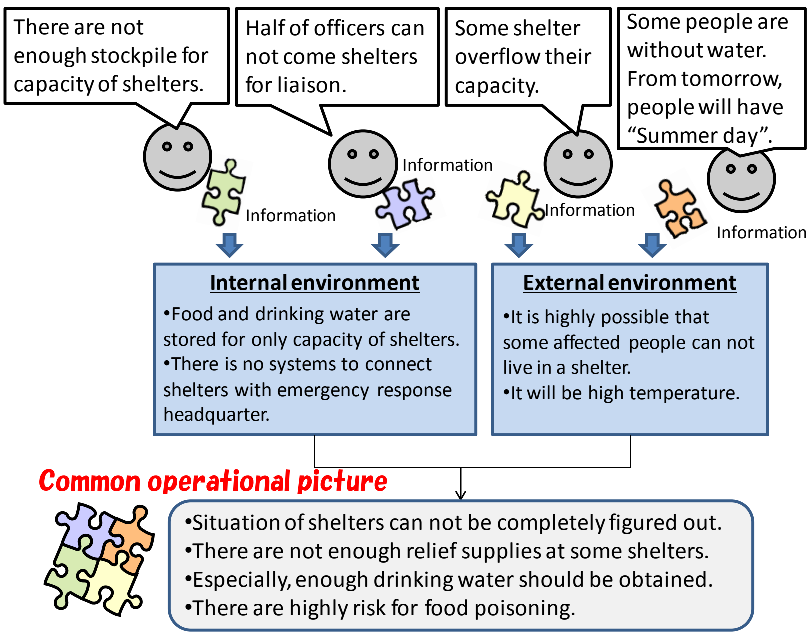

Figure 2: The process for sharing common operational picture

There are three reasons for sharing the common operational picture instead of the fragmented information. First, it is possible to make decisions from the point of view of all affected areas. Second, it is possible to respond proactively with future forecast. Third, it is easy to set objects and to gain understanding of the relevant players. This point will be covered in detail later.

2.2 Developing action plan with strong objectives

It is necessary that emergency response headquarters make an action plan with strong objectives. The action plan is composed of hierarchical attainable objectives and action policies for achieving objectives. "Objectives" makes clear the desired situation for the community with "by when", "who / where", and "how far emergency response headquarters improve". "Action policies" makes clear the direction the organization should go and promote relevant players for achieving objectives. According to the action plan, divisions within the organization should respond and coordinate with other divisions. Figure 3 shows an example of action plan. At first, operations divisions and field sites should consider strong objectives with future forecast from a global point of view, and following that action policies for achieving the objectives are decided.

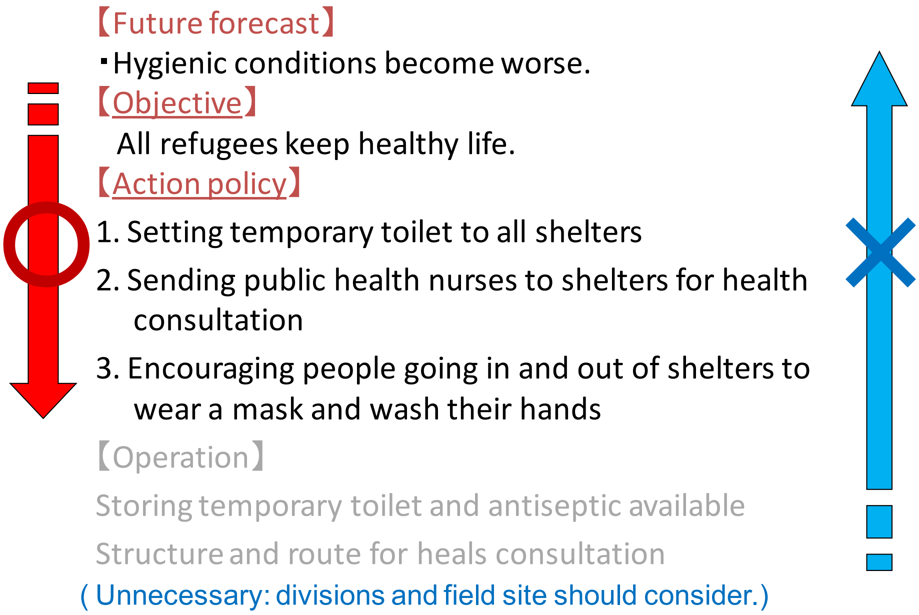

Figure 3: An example of action plan

For making the action plan, there are three points to pay attention to. Firstly, objects are measurable. Objects are clear by when and how far to do, not abstract such as "Quick recovery and reconstruction". Secondly, objects give operations for achieving objectives flexibility. Decision of operations is left to field site. Thirdly, expression of objects is short and to the point. This way, all members easily respond with discipline.

There are four advantages of making an action plan with strong objectives. First, affected people's reliability is improved because they can have a clear vision for the future. Second, action policies are made in top-down style, so staff members understand the position of operations and become a highly-motivated team. Third, it is possible to respond depending on the time and situation because operational decisions for achieving objectives are left to the field site. Forth, emergency response headquarters can get support from relevant organization such as public institution, press, volunteer, and companies because it is easy to understand the contents of action.

2.3 Conducting strategic public relations

A lot of press visit affected area in emergency situations, and emergency response headquarters of local governments become one of the places for press coverage. The more massive and highly concerned the crisis, the more difficult it is to do operations for achieving objectives under the public relations. For example, TV camera comes into the operations place, and the head of division who should lead operations is very busy with press coverage. Almost all local governments do not clearly position public relations as emergency operations and, as a result there is no professional public relations officer at emergency response headquarters in emergency situations.

"Strategic public relations" means putting out the information to citizens aggressively using press for achievement of objectives. This is different from passively answering questions from the press. For instance, when a fire breaks out in a factory due to earthquake, giving only the fact of notice to the press makes it difficult for recipients such as the press and audience to recognize the content and to understand and take actions. Therefore, the press asks about "What will people living around the fire do?" and "What will emergency response headquarter operate in the situation?" The answers for them depend on action plan with strong objectives. For example, it is necessary to know whether the fire on the factory spreads or hazardous materials catch fire for sharing common operational pictures. In the former case, no risk of burst and fire spread is delivered and the message of acting in a level-headed manner is put out. In the latter case, emergency response headquarters delivers a risk of second accident and puts out a message for evacuate procedures. Therefore, the contents of public relations are decided according to action plan and the public relations division and emergency response headquarter should respond together.

3. EXAMPLE OF TRAINING COURSE BASED ON SEMO

To evaluate the effectiveness of SEMO an exercise based on SEMO was conducted at DRI. The main target of this course was the disaster response officer of local government, the purpose was to learn management by objectives. Participants consisted of 13 people from prefectural governments and 26 people from municipality. Operators consisted of 3 people as designers of course and exercise, 5 people as the role of journalist, 3 people as the role of chief, and 3 people as logistic supporters. The length of this course was two days and optional orientation was conducted for applicants to understand the background for designing this course.

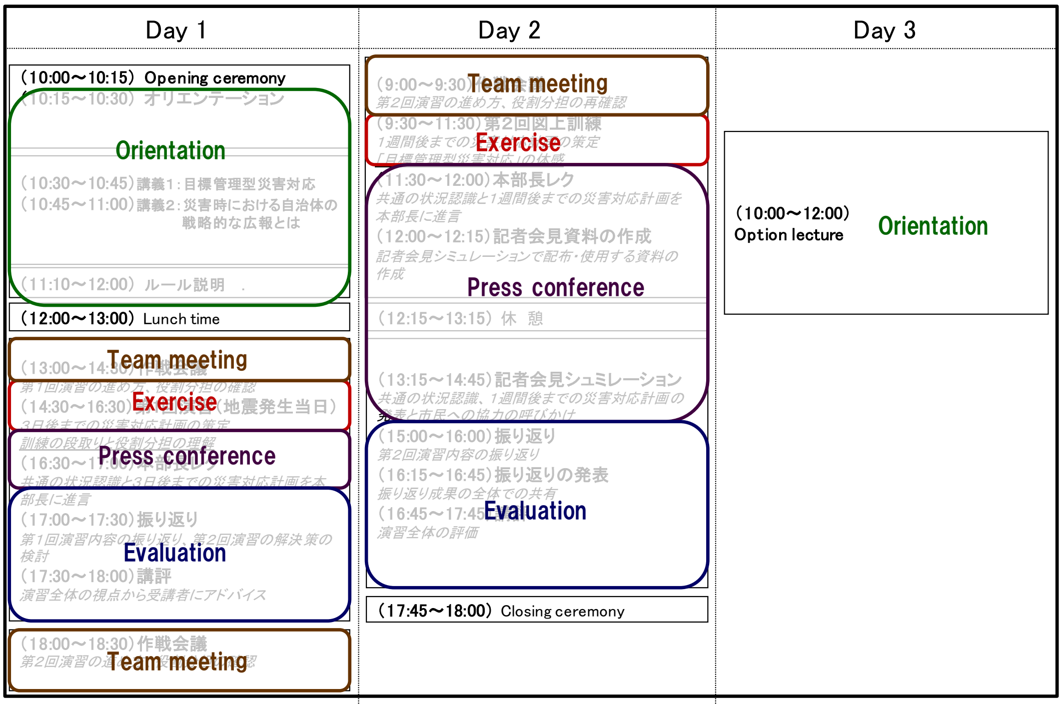

Figure 4: Curriculum of the training course at DRI

Three constrained conditions to design a curriculum are given as follows. First, participants come from all over the country because their area characteristics, frameworks of emergency response headquarter, and working method are different. Second, the rules of the exercise take time to understand. Third, two days are ensured for this training course.

Four concepts to design a curriculum according to constrained conditions are given as follows. First, forming three groups (one prefecture and two municipalities), a participant respond with other participants whose area characteristics, frameworks of emergency response headquarter, and their working method are similar. Second, participants are provided orientation to understand the settings and rules of exercise. Third, participants have time to decide arrangements for response in exercise with team meeting. Forth, the scenario for the exercise is a huge earthquake disaster and the exercise is conducted twice. The purpose of the first try for participants is to get used to the rules of the exercise. For the first exercise, the scenario assumes four hours have passed since the earthquake happened, and participants make an action plan with objectives for three days after the earthquake happened. For the second exercise, the purpose is for participants to realize management by objectives, and the scenario assumes three days have passed since the earthquake happened. Participants make an action plan with objectives for one week after earthquake happened. Figure 4 shows a curriculum of this training course based on these concepts to design. Participants repeat the sequence; "team meeting" "exercise" "simulated press conference" and "evaluation", twice after first orientation.

In the training course, participants learned the purpose of this course and rules of the exercise with concentration through first team meeting, exercise, and evaluation. In the second exercise, participants respond according to management by objects based on this experience. For example, participants shared common operational pictures such as writing a situation on a post-it and putting the post-it on a whiteboard (Figure 5). They organized action policies according to problems in the affected area for making action plan with objectives (Figure 6), and they conducted strategic public relations using maps with journalists (Figure 7). If some participants had not yet understood the purpose of this training course, then the exercise designers coached them. During the simulated press conference, participants announced their own action plan with objectives one week after earthquake happened to journalists (Figure 8). After the simulated press conference, each group looked back at their response and made a presentation summarizing the content of their self-view according to the three principles of management by objectives. Finally, the roles of journalist and designers of exercise evaluated and commented on the response and presentation of participants.

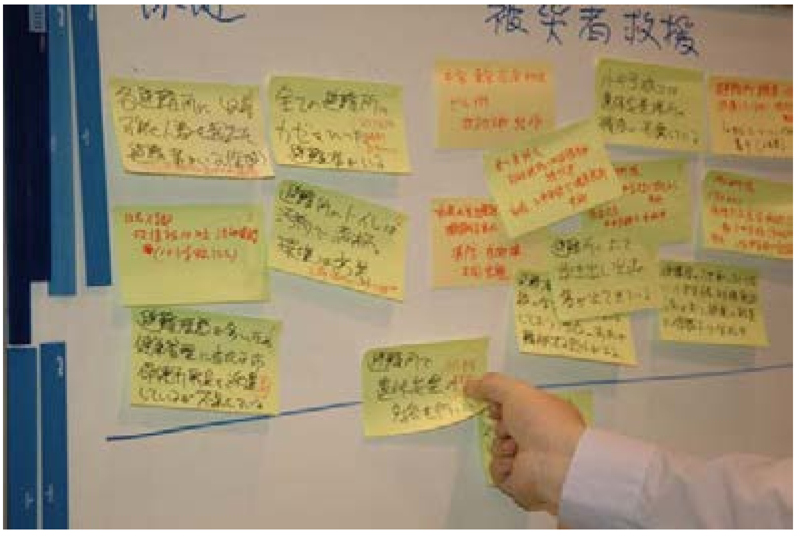

Figure 5: Scene of exercise (Sharing common operational picture)

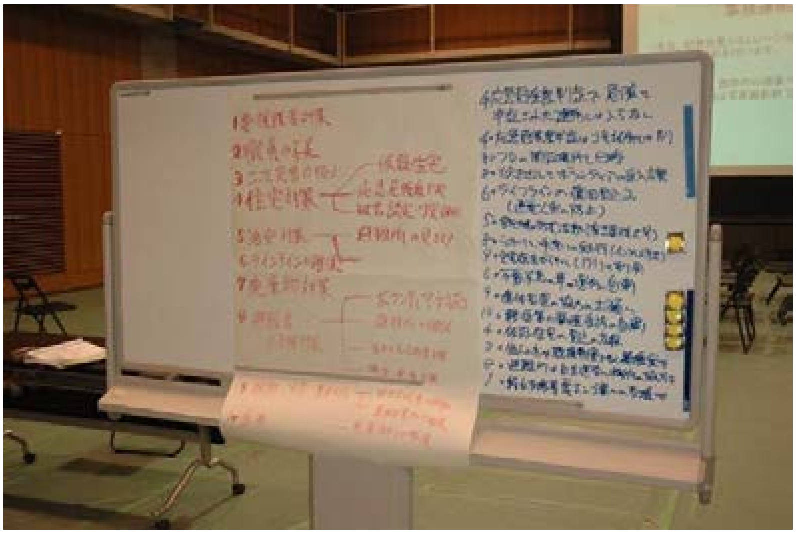

Figure 6: Scene of exercise (Developing action plan with strong objectives)

Figure 7: Scene of exercise (Strategic public relations)

Figure 7: Scene of simulated press conference

From the investigation on participant satisfaction, the average score was 90 out of 100 (quantity of response was 37 people). This shows that the participants were satisfied with the training course at DRI based on the trend that participants had lower satisfaction even when they failed but they were still satisfied with the training course.

The authors also surveyed awareness of management by objectives for achieving the purpose of SEMO. As a result, almost all participants answered they benefited greatly from this training course. Some participant replied that they understand the importance of management by objectives and will try to apply SEMO to their disaster training course of local government.

4. CONCLUSION

DRI developed a simulation exercise for emergency response headquarters, management by objectives (SEMO). In this paper, an outline of three principles of management by objectives and an exercise conducted at DRI based on SEMO were introduced. As a result, participant satisfaction was improved and participants could understand management by objectives. SEMO is an effective exercise for emergency response officials to learn how to manage an emergency response headquarters.

REFERENCES

Kondo, S., Hiruma, Y., Meguro K., and Kawata, Y., 2009. Analysis of organizational disaster response of the local government at the operation-based exercise. *JSCE Journal of Earthquake Engineering* Vol. 30, 710-716.
Kondo, T., Koshiyama, K., Hayashi H., Fukutome K., and Kawata, Y., 2006. Emergency Management and Common Operational Picture of Emergency Operation Center in Niigata Prefecture in the 2004 Mid-Niigata Prefecture Earthquake : Analysis from Management by Objective perspective. *Journal of social safety science* (8), 183-190.
Kondo, T., and Nagamatsu, S., 2007. Emergency Response applying Incident Command System by Local Government : A case study on 2005 Hurricane Katrina Disaster. *Journal of social safety science* (9), 253-260.

The Study of the Residents' Demands for Fire Escape--Illustrated by Two Senior Citizen Homes-

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ABSTRACT

The study aims to investigate fire escape behaviors derived from residents in senior citizen homes and then to analyze the demands for fire escape. Taipei Mucha Self-paid residential home and Taipei Municipal Haoran Senior Citizen Home were chosen as study sites. The results find that over 50% of senior residents considered the current fire alarm system sufficient for their needs while 25% of senior residents expected to install a fire alarm with a louder horn to wake them up on each floor. The greatest number of senior residents chose to take their nearest stairs as the best method to come to fire safety. Meanwhile, they also chose their nearest elevators or stairs for safe evacuation. When asked to determine the measures to help residents escape from a fire, the majority of senior residents chose adding interval horizontal platforms, followed by strengthening the function of elevators to meet the requirements of emergency elevators. These two options can be further studied and then served as the guidelines for fire safety in order to secure senior citizens from a fire emergency.

Key words*: senior citizens, senior citizen home, fire escape, escape behavior,*

1. INTRODUCTION

Any disaster that might occur at any time or place is undoubted. How to reduce the personnel casualty and the belonging loss in a disaster becomes a major problem, but preventing the personnel casualty is primarily important. The design of the facility and advanced equipment for fire safety would help alter the situation. Furthermore, the facility design can be improved by the assessment of safety evacuation theories. Senior citizens and their housing such as senior homes or health care facilities have been inseparable since an aging society approached. All in the society should pay close attention to safety issue.

The increase of senior citizens results in an aged society in Japanese. This urges many researchers or professionals to pay great efforts and concerns for the study or investigation of evacuation plan for senior population. The topics are various. The study of installation of horizontal zone concludes that occupants might only take half of evacuation time to reach a safe zone in an emergency, which slightly affect occupants who are able to walk independently. At the same time it decreases half number of occupants who are in danger and surely creates a spacious waiting zone. Since the capacity of fire zone become smaller, It's important that venting equipment and bedroom zoning should be carefully planned(矢代嘉郎,掛川秀史,海老原學,大槻明 & 岩城英朗,1993).

To investigate the building types, ways of evacuation, interior design for fire safety and fire alarm system is another focus among the studies(室崎益輝、大西一嘉、久次米真美子、多田純治 & 伊場圭司, 1988). 376 eldercare facilities specializing in extended care or assisted living and 491 health care organizations on disability were included. The mailed questionnaires were completed by those who are responsible for evacuation in the event of a fire or other emergency. The results conclude that buildings used by the majority of senior own three characteristics in common. First, the building layout caused users themselves not to be able to evacuate for fire safety. Secondly, it ‘s difficult for building staff members to have a priority over to try to put off at the first stage of fire, to call fire department, or to help those who are supposed to be taken care of. Thirdly, it’s difficult for staff members quickly to know the occurrence of a fire and to notify users of the fire, especially in the evening. .

The simulation test was designed to measure staff member reaction toward a fire at its early stage(室崎益輝,大西一嘉,久次米真美子,多田純治 & 伊場圭司, 1988). If these organizations determined only one position in charge of fire safety program, they concluded that it might take 2-3 minutes to put off a fire at its early stage while one minute for notification and two minutes for passing the message. After a total of 4-5 minutes past, the staff member started to take a further step to lead the users to evacuate. As for the evacuation ability in disadvantages groups, what users with or without the independent or the dependent waking ability experienced in the drill was taped to quantify their evacuation ability(室崎益輝,大西一嘉,久次米真美子,多田純治&伊場圭司, 1988). Users’ evacuation speed and time consumed for preparation and setting up fire safety equipment provided by helpers were concluded to assess the overall evacuation ability. Obviously, accessibility and capability of equipment for fire safety became more important to both staff members and building users.

Many authors in Taiwan has been engaged in the pace and cluster density theory study for over 10 years. The results tried to establish the local evacuation data based on general population, and the study sites contained hospitals, auditorium for concert, train station and MRT main station(Yang & Lin, 1999；Ho & Jian, 1999；Ho& Cheng, 1999; Lai,2001). As for senior residents in disadvantage groups such as seniors, the first study of evaluation of the evacuation safety design for five senior rest homes in Taipei metropolitan area was found. The residents were divided elders into healthy, walking stick users, and wheelchair users. The results concluded the average of horizontal and vertical walking speed of seniors (Tsai, 2001). The other study also focused on the three different kinds of mobility users in 10 senior citizens homes of central and southern part of Taiwan. The results provided with basic evacuation data (Lin, Hsu &Cheng 2001). Not only horizontal and vertical walking speed but also the N_{eff} value was derived from the residents in there senior citizens homes sponsored by Taipei Municipal Government.(Huang, 2002, 2007).

Based on the idea of respecting each human life, the fire protection design in a building is ultimately to help all the occupants or users escape to safe areas. However, current acts or regulations relevant to building design and fire protection design are mainly enacted for the interests of general public. Since no studies of fire escape specializing in disadvantages groups have been found, there is an intensive need to collect what they require or how they behave for safe escape. The results expect to indicate the weaknesses in current building acts and fire acts, which inspire the public pt pay close attention to these groups and provide designers with guideline for designing their living and activity environments. Eventually, it's also believed that the results will help amend relevant acts or regulations in the future. The purpose of the study is to identify what seniors need for fire escape.

2. RESEARCH METHODS

The research is designed to investigate senior fire escape behavior and senior profiles in two senior homes of Taipei. The study subjects were occupants in Taipei Mu-cha Self-paid residential home and Taipei Municipal Haoran Senior Citizen Home. The questionnaire was in three parts. The first part of the questionnaire focused on items of horizontal and vertical moving ability and capability of using the extinguisher. The second part was to investigate behavior patterns concerning moving types, awareness of fire, reaction toward the early stage of a fire and a large fire and the demands for safe evacuation. The final part contained questions regarding a respondent's gender, age, education, occupation before retirement, exercise hours per day and moving ability. From June 1 to July 31 of 2009, a total of 246 questionnaires were distributed to the residents in these two senior homes. The data were transferred from the questionnaire and calculated by the SPSS statistic computer package. The frequency and Chi-square test were used in the study.

3. RESULTS AND DISCUSSIONS

Response rate was 85% in Taipei Mu-cha Self-paid residential home while91% in Taipei Municipal Haoran Senior Citizen Home.

3.1 Senior resident profiles

Of the 225 senior residents, 47.6 percent were male and 52.4 percent were female. The majority of them were between at the age of 81 and 90 (45.3%), followed by those at the age of 71-80 (34.7%). Residents at senior high school level (24%), illiterate (18.2%) and elementary level (18.2%) were major groups in education classification. As for the occupation before retirement, the major groups were residents without working experience (18.7%), professional (17.8%) and service-man (13.6%). Over 60.4percent of them spent less than 1 hour doing exercise, followed by 31.1 percent with 1-2 hours within. Based on the mobility levels of the residents, 56 percent of them were able to walk independently only, followed by 19.1 percent of them were able to walk and run independently, 18.2 percent with walking sticks and 6.7 percent with wheelchairs

Table 3-1 Senior Resident Profiles

	N=225	%
Gender		
Male	114	47.6%
Female	111	52.4%
Age		
Under 70 years old	23	10.2%
71-80 years old	78	34.7%
81-90 years old	102	45.3%
Over 91 years old	22	9.8%
Education level		
Illiteracy	41	18.2%
Self-study	19	8.4%
Elementary graduate	41	18.2%
Junior high school graduate	24	10.7%
Senior high school graduate	54	24.0%
2-year-college graduate	13	5.8%
College or University graduate	31	13.8%
Graduate	2	0.9%
Occupation before retirement		
Public opinion representative/Manager	7	3.1%
Professional	40	17.8%
Employee work for professional	25	11.1%
Fisherman /Farmer	5	2.2%
Technician	24	10.7%
Serviceman	31	13.6%
Employee in service industry	25	11.2%
Non-technician	26	11.6%
Without working experience	42	18.7%
Length of daily Exercise		
Within 1 hour	136	60.4%
1-2 hours within	70	31.1%
2-3 hours within	13	5.8%
3-4hours within	4	1.8%
Over 4 hours	2	0.9%
levels of mobility		
To walk and run independently	43	19.1%
To walk independently only	126	56.0%
Auxiliary aids such as walking sticks	41	18.2%
Wheelchairs	15	6.7%

3.2 Resident mobility in senior homes

When asked the place where they took a break if they went downstairs, Table 3-2 shows two major groups were those who reached to the 6th floor (40.9%) and to the 1st floor (28.9%). Residents took 1-2 minutes within for a break (41.38%) was the major group while the second major group with a break of 2-3minutes within (23.1%).As for hand-held portable extinguishers, 44.4% of the residents were able to hold smaller than a 10-pound extinguisher, and the following were24.4% with holding a 10-pound extinguisher, 19.1% with holding larger than a 20-pound extinguisher, and 12% with holding a 20-pound extinguisher.

Table 3-2 Resident Mobility in Senior Homes

	N=225	%
A break needed to take while going down the stairs from 7th floor		
to the 6th floor	92	40.9%
to the 5th floor	36	16.0%
to the 4th floor	6	2.7%
to the 3rd floor	23	10.2%
to the 2nd floor	3	1.3%
to the 1st floor	65	28.9%
Time for the break		
1-2 minutes within	94	41.8%
2-3 minutes within	52	23.1%
3-4 minutes within	15	6.7%
4-5 minutes within	19	8.4%
5-6 minutes within	13	5.8%
over 6 minutes	32	14.2%
The fire extinguisher weight the senior residents can hold		
Over 20 pounds	43	19.1%
20 pounds	27	12.0%
10 pounds	55	24.4%
Below 10 pounds	100	44.4%

3.3 Senior residents' behavior and fire safety

When asked how to move vertically in their senior homes, Table 3-3 indicates that 74.2 percent of the residents took elevator in both directions, followed by 13.8 percent with using stairs in both directions, which were two groups representing the majority of senior residents. 72.4 percent of the residents thought they were capable of putting off a small fire, while 51.1 percent would go to the staff members in the nearest service station to ask for help as they encountered a large fire. Another option is 34.2 percent of them would push down the nearest PBL to give a signal. When the residents reviewed fire alarms, 50.2 percent of them thought that current equipment was adequate. The rest of them expect a fire alarm with horn installed on each floor and its volume enlarged (24.2%), followed by staff members knocking doors to give warnings (20.4%).

The best way they chose to evacuate in a event of fire was self-approach to the nearest stairs (55.6 %). For other options, 18.7 percent of the residents chose to take elevators. The places for safe evacuation they chose were the nearest stairs or elevators (22.2%) and public areas (18.2%). These two groups represented the majority of senior residents. Only 18.2 percent of the residents were unable to evacuate by themselves and 10.2 percent of the residents were unsure to have evacuation ability. This distribution indicates that over 60% of the residents were capable of evacuating. As for the facilities benefiting their evacuation for fire safety, to add interval horizontal platforms chosen by 115 residents and all elevators to meet the requirements of emergency elevators chosen by 98 residents represented what the majority of them would like to have.

Table 3-3 Senior Residents' Behavior and Fire Safety

	N=225	%
Vertical moving types		
To use the stairs in both directions	31	13.8%
To take elevator up and go down the stairs	23	10.2%
To go up the stairs and take elevator down	4	1.8%
To take elevators in both directions	167	74.2%
Ability to put off a small fire		
Be able to do it	163	72.4%
To ask someone for help	31	13.8%
To cry loudly for help	19	8.4%
To inform the service station of getting a help	12	5.3%
In an event of a large fire		
To Inform service station of a fire and ask for help	115	51.1%
To push down PBL	77	34.2%
To stay right there and wait for rescue	28	12.4%
Others	5	2.2%
Fire alarm / improvement		
A fire alarm with horn and its volume can be enlarged	55	24.2%
To ensure fire alarm heard in the room and to add the installation of visual notification appliances	7	31.0%
A fire alarm with visual notification appliances installed on the top of nightstand in the room	4	1.8%
Current equipment adequate	113	50.2%
Staff members to notify by knocking doors	46	20.4%
The best way to evacuate		
To take elevators	42	18.7%
Self-approach to the nearest stairs	125	55.6%
To stay in balcony for rescue	15	6.7%
Self-approach to a service station on each floor	19	8.4%
Someone come to help lead the way out expected	24	10.7%
Places for safe evacuation		
Toward public areas	50	22.2%

Toward the nearest elevators or stairs	110	48.9%
To wait in the balcony for rescue	6	2.7%
To wait in the bathroom for rescue	1	0.4%
To wait for staff members to take a lead	40	17.8%
To follow the other residents	18	8.0%
Ability to evacuate		
Yes.	161	71.6%
"No, need someone guided"	41	18.2%
"I don't know, It depends"	23	10.2%
The improvement of facility and equipment for fire safety		
To strength the elevator function to meet the requirements of emergency elevators	98	
To add a safety zone in the building	52	
To sponsor training program of fire safety for staff members.	85	
To add interval horizontal platforms	115	
To add spaces for refuge and escape in balconies	67	
Cell phone with GPS system and special service for emergency	7	
Others	4	

3.4 Chi-square test of independence

Chi-square test of independence was applied to examine whether each of the resident profile variables with each of behavior pattern variables were related. The results indicated gender classification and the weight classification of portable extinguishers were associated (Tab3-4). It also indicates age classification and each of the following classifications—vertical moving types, the demand for alarm equipment and evacuation area were associated.

As the cross table is examined, Table 3-5 shows that the greatest number of the residents (44.4%) were capable of holding smaller than a10-pound extinguisher. Among them, 70 percent were female and 30 percent are male. It might infer that the female residents were unable to hold larger than a 10-pound extinguishers because of their physical conditions.

As the cross table is examined, Table 3-6 demonstrates that the greatest number of the residents (74.2%) took elevators to move vertically. It consisted of 81.5 percent of residents above the age of 80 and 65.3 percent of the residents below or at the age of 80. It's found that the older the residents took elevators the more.

Table3-7 shows the distribution of fire alarm/ and its improvement and gender Classifications. For the group below or at the age of 80, the greatest number of the residents (53.5%) considered that the equipment was adequate, followed by those who needed to enlarge its volume (28.7%). For the group above the age of 80, most of the residents (47.6%) also considered that the equipment was adequate, followed by knocking doors expected (27.4%).

As the cross table is examined, Table 3-8 indicates that places for safe evacuation, the greatest number of the residents in both age groups approached the nearest elevators or stairs with 52.5% and 46%, respectively. The second major group in age classification also demonstrated the same result. 24.8 percent of the residents above the age of 80 and 20.2 percent of the residents below or at the age of 80 went to public areas.

Table 3-4 Chi-square Test of Independence

Variable 1	Variable 2	Pearson Chi-square value	Degree of freedom	ρ value	Significance
GENDER	The weight of portable Extinguisher	35.847	3	0.000	*
	Vertical moving types	5.802	2	0.055	
	Ability of putting off a small fire	3.980	3	0.264	
	In an event of a large Fire	(×)	(×)	(×)	
	Fire alarm/ Improvement	0.310	3	0.958	
	The best way for Evacuation	7.386	4	0.117	
	Places for safe evacuation	0.530	4	0.970	
	Ability of evacuating	1.117	2	0.572	
AGE	The weight of portable Extinguisher	4.287	3	0.232	
	Vertical moving types	9.019	2	0.011	*
	Ability of putting off a small fire	1.067	3	0.785	
	In an event of a large Fire	(×)	(×)	(×)	
	Fire alarm/ Improvement	8.738	3	0.033	*
	The best way for evacuation	5.221	4	0.265	
	Places for safe evacuation	10.368	4	0.035	*
	Ability of evacuating	0.775	2	0.679	

* Statistically significant at $\rho<0.05$ level.

× Represents that more than 20% of the expected values may be less than 5

Table3-5 Cross Table for the distribution of Fire Extinguisher Weight and Gender Classifications

Variable 1 \ Variable 2			Fire Extinguisher Weight				Total
			Over 20 lb.	20 lb.	10 lb.	Below 10 lb.	
GENDER	Male	Frequency	34	19	31	30	114
		R%	29.8%	16.7%	27.2%	26.3%	100.0%
		C%	79.1%	70.4%	56.4%	30.0%	50.7%
	Female	Frequency	9	8	24	70	111
		R%	8.1%	7.2%	21.6%	63.1%	100.0%
		C%	20.9%	29.6%	43.6%	70.0%	49.3%
Total		Frequency	43	27	55	100	225
		R%	19.1%	12.0%	24.4%	44.4%	100.0%
		C%	100.0%	100.0%	100.0%	100.0%	100.0%

Table3-6 Cross Table for the Distribution of Vertical Moving Types and Gender Classifications

Variable 2 / Variable 1			Vertical Moving Types			Total
			To use the stairs only	Either the stairs or elevators	To take elevators only	
AGE	≦ 80	Frequency	21	14	66	101
		R%	20.6%	13.9%	65.3%	100.0%
		C%	67.7%	51.9%	39.5%	44.9%
	> 80	Frequency	10	13	101	124
		R%	8.1%	10.5%	81.5%	100%
		C%	32.3%	48.1%	60.5%	55.1
Total		Frequency	31	27	167	225
		R%	13.8%	12.0%	74.2%	100%
		C%	100%1	100%	100%	100%

Table3-7 Cross Table for the Distribution of Fire Alarm /improvement and Gender Classifications

Variable 2 / Variable1			**Fire Alarm /Improvement**				Total
			1.	2	3	4.	
AGE	≦ 80	Frequency	29	6	54	12	101
		R%	28.7%	5.9%	53.5%	11.9%	100.0%
		C%	52.7%	54.5%	47.8%	26.1%	44.9%
	> 80	Frequency	26	5	59	34	124
		R%	21.0%	4.0%	47.6%	27.4%	100%
		C%	47.3%	45.5%	52.2%	73.9%	55.1%
Total		Frequency	55	11	113	46	225
		R%	24.4%	4.9%	50.2%	20.4%	100%
		C%	100%	100%	100%	100%	100%

1 representing a fire alarm with horn installed on each floor and its volume enlarged
2 representing to ensure fire alarm heard in the room and also install visual notification appliances
3 representing current equipment adequate
4 representing that staff members to notify by knocking doors

Table3-8 Cross Table for the Distribution of Places for Safe Evacuation and Gender classifications

Variable2 / Variable1			**Places for Safe Evacuation**					Total
			1	2	3	4	5	
AGE	≦ 80	Frequency	25	53	4	9	10	101
		R%	24.8%	52.5%	4.0%	8.9%	9.9%	100.0%
		C%	50.0%	48.2%	57.1%	22.5%	55.6%	44.9%
	> 80	Frequency	25	57	3	31	8	124
		R%	20.2%	46.0%	2.4%	25.0%	6.5%	100%
		C%	50.0%	51.8%	42.9%	77.5%	6.5%	55.1%
Total		Frequency	50	110	7	40	18	225
		R%	22.2%	48.9%	3.1%	17.8%	8.0%	100%
		C%	100%	100%	100%	100%	100%	100%

1 to representing the public areas
2 representing to approach the location of the nearest elevators or stairs
3 representing to wait in the room for rescue
4 representing to wait for staff members to take a lead
5 representing to follow the other residents

4. CONCLUSIONS

1. The research indicate that 72 percent of senior residents were capable of putting off a small fire while 51 percent would go to the nearest service station for help as a large fire occurred.
2. When asked for the demand of fire alarm, over 50 % of senior residents thought that current equipment was adequate and 25 percent expected a fire alarm installed on each floor and its volume enlarged.
3. As for the usage of fire extinguisher, the Chi-square test demonstrates that the weight of fire extinguisher and three respective variables--gender, length of daily Exercise and levels of mobility were not independent. As the cross table is examined, it shows that 84.7 percent of female senior residents were unable to carry larger than a 10-pound extinguisher because of the limitation of their physical condition.
4. When asked how to evacuate properly to safe areas, the majority of senior residents were capable of approaching to the nearest stairs by themselves. Those who chose to take elevators become the second major group. Similarly, around 71.6% of senior residents considered that they were able to evacuate, and most of them chose the location of the nearest elevators or stairs.
5. As for the measures of enhancing safety level of fire protection, the majority of senior resident considered to add interval horizontal platforms, followed by to strengthen the function of elevators to meet the requirements of emergency elevators.. The results are expected to provide the information to amend the acts or regulations relevant to building design for fire protection.

REFERENCES

Chen, C. C. & Jian, S.W., 2008.*Handbook of Performance-based Design Method for Fire Safety Design Code of Building*. Architecture & Building Research Institute, Ministry of Interior.

Ho, M. J.,& Chang. C.C., 1999. A Preliminary Research of Disaster Aversion on Building Types and User Behaviors—Taking Department Stories as an Example, *Architecture & Building Research Institute Case Study Report*

Ho, M. J. & Jian, S.W. , 1999. An Investigation on the Mass Evacuation Characteristics of Earthquake Disasters in Taiwan, *Architecture & Building Research Institute Case Study Report*

Huang, C.H. , 2002. Research on the Horizontal Escape Speed of the Aged －－ illustrated by three senior nursing homes in Taipei－－, *Master Thesis, Dept. of Arch., National Taiwan University of Science and Technology*.

Huagn, C.H., 2007. The Study of Senior Moving Ability Applied to Evacuation Plan Verification, *Doctoral Dissertation, Dept. of Arch., National Taiwan University of Science and Technology*.

Lai, Y. S., 2001.General and Emergency Evacuation in Pedestrian Flow Analysis and Mode Establishment for Passage and Stairway, *Doctoral Dissertation, Dept. of Civil Engineering, National Taiwan University*

Lin, C.Y., Hsu, M. H., & Cheng, S. T., 2001. Survey for the Evacuation Data in Senior Welfare Institute , *Proceedings of the 13th Taiwan Architect Association*

Architecture Study Conference Report.
Tsai, S. F. , 2001. Study for the Evacuation Safety Design in the Senior Rest Home, *Master Thesis , Department of Architecture, Tan-Kang University*
Yang, I.Y. & Lin, C.Y., 1999. The Study on the Design and Plan for the Hospital Facilities of Disaster Evacuation, *Architecture & Building Research Institute Case Study Report*
矢代,嘉郎; 掛川,秀史; 海老原,学; 大槻,明; 岩城,英朗,1993.高齢者施設における水平避難方式の効果 : 災害弱者施設の火災安全対策(その 4)学術講演梗概集. A, 材料施工,防火,海洋,情報システム技術 1993,1341-1342,19930725 (社団法人日本建築学会)
室崎,益輝; 大西,一嘉; 久次米,真実子; 多田,純治; 伊場,圭司, 1988.老人, 身障者福祉施設の避難計画に関する研究 : その 1 アンケート調査にみる防災体制の実態学術講演梗概集. E, 建築計画, 農村計画 ,567-568,19880901 (社団法人日本建築学会)
室崎,益輝; 大西,一嘉; 久次米,真実子; 多田,純治; 伊場,圭司, 1988.老人, 身障者福祉施設の避難計画に関する研究 : その 2 管理者の初期対応行動の定量化学術講演梗概集. E, 建築計画, 農村計画 1988,569-570,19880901 (社団法人日本建築学会)
室崎,益輝; 大西,一嘉; 久次米,真実子; 多田,純治; 伊場,圭司, 1988.老人, 身障者福祉施設の避難計画に関する研究 : その 3 弱者の避難行動能力の定量化学術講演梗概集. E, 建築計画, 農村計画 1988,571-572,19880901 (社団法人日本建築学会)

A study on the decrease in tourism to regions affected by natural disasters

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ABSTRACT

When a natural disaster happens within or around tourist spots, the number of tourists decreases even if there is no damage or the region is recovered. In previous studies, it was said that harmful rumors and restraint are the major reasons of the decrease, but surveys from the viewpoint of tourists are insufficient. In this paper, the decrease in tourism to regions affected by natural disasters is studied by conducting surveys through a case study and by opinion poll. The survey results show that the main reason for the decrease is the perception that "it seems dangerous," which is not based on the real situation. Information on the situation in affected regions should be properly distributed, especially to people living in other prefectures, but it was found that in reality little information was delivered. Experts or local organizations can be reliable as sources of information. It was found that most tourists are aware that travel would help support the tourism spots, but they cannot decide whether to go there because of lack of information. Thus, it is vital to provide information on safety and to spread support for tourism.

Keywords: *natural disaster, tourism, avoidance of visit, harmful rumor, opinion poll*

1. INTRODUCTION

In this paper, we propose countermeasures to the decrease in tourism to regions affected by a natural disaster based on surveys through a case study on the Iwate-Miyagi Inland Earthquake in 2008 and by opinion poll. When a natural disaster happens within or around tourist spots, the number of tourists decreases even if there is no damage or if the region recovers. In this paper, we call this decrease "holding back tourism". For affected regions and surrounding areas, damage from the decrease in tourism is enormous, particularly in addition to the direct damage such as casualties or collapsed houses. Damage on tourism has great influence on other industries because of its ripple effects. There are some previous reports about reconstruction of tourism after natural disasters by Ide (2006). In a study on the decrease in tourism by Sekiya (2003), it was said that harmful rumors and hesitation are the major reasons for the decrease, but surveys of mass media and from the viewpoint of tourists are insufficient.

2. CASE STUDY ON THE IWATE-MIYAGI INLAND EARTHQUAKE

We conducted a case study on the Iwate-Miyagi Inland Earthquake in 2008, after which it was said that the damage due to decrease in tourism was tremendous.

2.1 The earthquake information

We assembled information from the report by the cabinet office.
- Date, Time: Saturday, June 14, 2008 at 08:43:46 AM at epicenter
- Location: 39.122 degrees N, 140.678 degrees E (southern Iwate Prefecture)
- Depth: 8km
- Magnitude: 7.2
- Maximum seismic intensity: 6+ in Japanese intensity scale
- Casualties: 17
- Totally collapsed houses: 23

2.2 Newspaper survey

We investigated newspaper articles about the earthquake from the day it happened to the end of the year. Using “Kikuzo 2 visual”, we counted the number of articles of the national edition and Miyagi edition of Asahi Shimbun. Articles are classified into four categories: damage and refuge life, support and administration, safety and reconstruction, other (Figure 1).

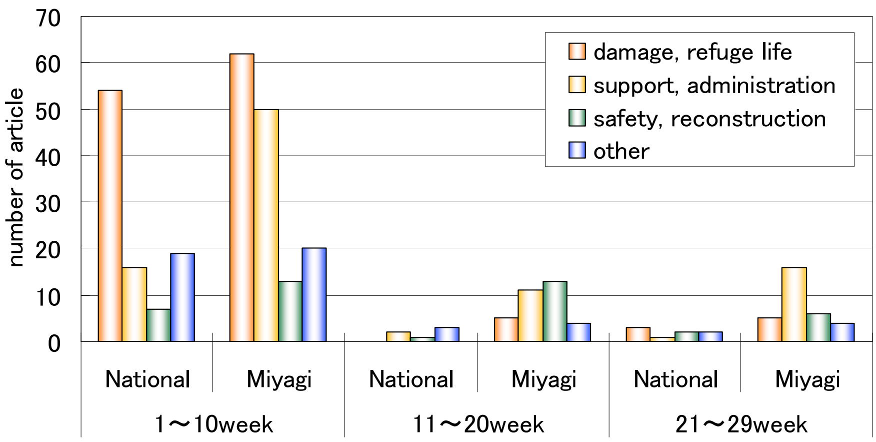

Figure 1: Transition of the number of articles

Just after the earthquake occurred, the number of articles about damage and refuge life was very large. However, in the national edition, the number of articles about safety and reconstruction was small, and after 11 weeks, there were few articles about the earthquake. In the national edition, most articles are about damage and refuge life and provided only within 10 weeks.

2.3 Survey on statistics

Figure 2 shows the transition of the number of tourists to Hanamaki city of 2007 and 2008 classified by origin (from inside or outside of the prefecture). The data was obtained from tourism statistics of Iwate.

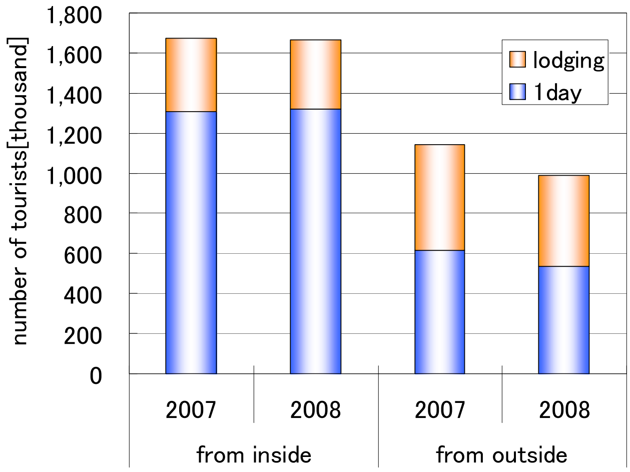

Figure 2: Transition of the number of tourists to Hanamaki

The number of tourists from outside of the prefecture decreased remarkably compared with that from inside. Moreover, when classifying tourists from outside into 1 day and lodging, the decrease of lodging tourists was larger than that of 1 day tourists. The same tendency was observed in other cities. Focusing on the number of lodging tourists, based on the Japan Tourist Agency statistics, growth rates of lodging tourists by prefectures in 2008 (January to December 2008 compared to 2007) spread widely.

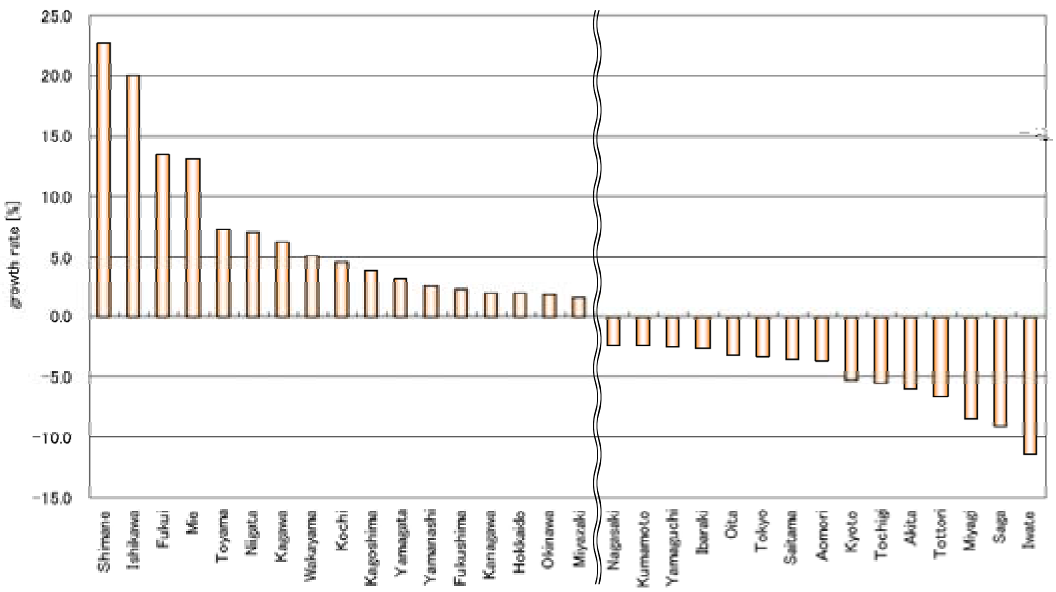

Figure 3: Growth rate of tourists by prefectures (2008 compared with 2007)

In Figure 3 it could not be seen that national tourism activities were stagnant. In the Tohoku area, Yamagata and Fukushima visitor numbers have increased compared to 2007, but three prefectures (Iwate, Miyagi, Akita) are included in the bottom five. Thus, the trend of decrease in the number of tourists seen in the particular areas was not the trend of Tohoku area or Japan. In the three prefectures of Iwate, Miyagi and Akita, there was no event considered to cause decrease of tourists excepting the Iwate-Miyagi Inland Earthquake. Therefore, the reduction in the number of lodging tourists was caused by holding back of tourism because of the earthquake.

2.4 Survey on local organization

We sent questionnaires by email to the department of tourism in the three affected prefectures (Iwate, Miyagi and Akita) and six cities (Oshu, Hanamaki, Sendai, Osaki, Senboku and Yuzawa). Responses were obtained from seven organizations. The first question asked "the causes of the decrease of tourists," and five organizations answered. The most common answer was "a lot of report of damage." In addition, many organizations answered "ambiguous recognition of location" and "lack of safety information," as factors related to harmful rumors. "Economic downturn" and "soaring oil prices" were also mentioned as factors. The second question asked "ideal tourists action at the time." This question was answered by all and the answer was "after confirming safety, wanted to come to travel." The four organizations said "the usual tourist activities would be supports," and "there are many safe areas, be calmly and get information."

We also investigated the rate of decrease of tourists and the amount of damage caused by holding back tourism. However, we couldn't compare the damage by holding back tourism with that of actual disaster situations because the way of calculating the amount of damage and counting the number of tourists vary with governments. For example, in Hanamaki, the number of cancellations was 1,679 and the amount of damage was 164 million yen, but in Osaki the number of cancellations was 1,456 and the amount of damage was 69 million yen. Even considering the differences in personal spending, this is too big a difference.

3. OPINION POLL ON THE INTERNET

3.1 Survey overview

We conducted a survey of 800 people living in Tokyo (men and women from 20 to 59) via the Internet (January 2010) on tourist activities around the affected areas after natural disasters. It was confirmed that a representative sample of the Tokyo population was met by chi-square test. The purpose of this survey was to reveal behavioral factors for holding back tourism after natural disasters and recognition on support activities to the regions suffered from holding back tourism. In this survey, 5% significance level was set. We discuss the results below, for which significant differences were found by statistical hypothesis testing.

3.2 Reason of cancellation

To the question of "Have you ever cancelled tourism after natural disasters?" 11.6 percent answered "yes". A third of them cancelled because of "it seems dangerous" (Figure 4). About one-third said that the reason was that the actual damage has occurred. On the other hand, "restraint for the affected areas" was answered by only 3.2 percent of respondents. “Restraint,” which was cited as a factor in holding back tourism in previous studies, was not a big factor.

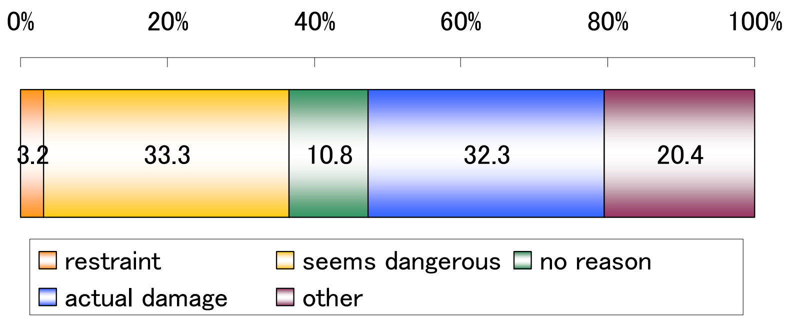

Figure 4: Reason of cancellation

Looking in more detail at the answers to this question, it is clear that there are gender differences in the response (Figure 5). Except "other", all answers showed a significant difference between the sexes. On one hand, women tend to cancel for "it seems dangerous" (41.5%), whereas on the other hand men cancelled due to "real damage" (36.5%). Compared to men, women cancelled because of dangerous image without the actual damage. Conversely, men tend to judge by the actual damage more than women.

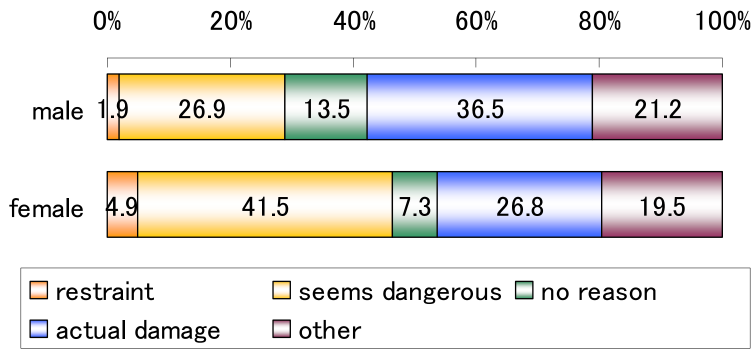

Figure 5: Reason of cancellation by genders

In this study, we consider "cancellation of tourism," regardless of whether the tourist visited other areas instead or canceled the tour itself, as holding back tourism if there was a decrease in tourists who originally planned to visit certain spots.

3.3 Tourism around affected regions

To the question of "Have you ever visit regions suffered by holding back tourism after natural disasters?" 20.0 percent answered "yes". Those respondents were asked the reason for the visit and the results are as follows (Figure 6). The answers are classified into six categories: curiosity, support, after check safety, as scheduled, visit relatives and other.

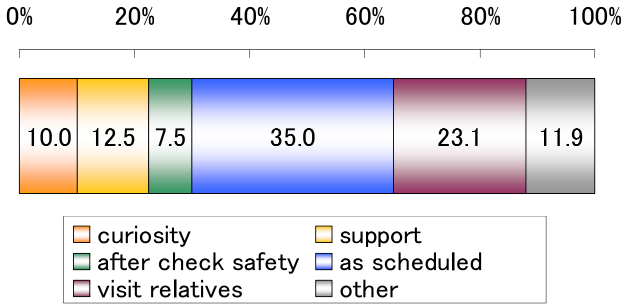

Figure 6: Reason of visiting affected regions

Most answers classified into "as scheduled" contain descriptions that they have confirmed safety. The answers "visit relatives" means they visited to support or check safety of their relatives, so it may include the purpose of support and the answers which said the purpose was support to other people are classified into “support.” In the “other” classification, the response “because thought that there were less people than usual” stood out. No answer included attractive public relations such as "enjoyable tourism information". Respondents who answered "after check safety" and "as scheduled" originally scheduled to visit there. On the other hand, respondents who answered "curiosity", "support", "visit relatives," "others" decided to visit there after natural disasters. To increase the visitors because of their relatives is difficult, but we may suppress holding back tourism to increase tourists who visit because of "curiosity", "support".

3.4 Reliability of information sources

We examined the reliability of safety information sources (Figure 7). We set six information sources: disaster response experts, local hotel association, city government, prefecture government, national government and travel agencies. For each these organizations, we investigated the reliability as a source of safety information. Results showed that disaster response experts are most reliable. In addition, local hotel associations are more reliable than the prefecture or national government. For tourists, the nearer to the affected region sources are the more the tourists believe the information is reliable.

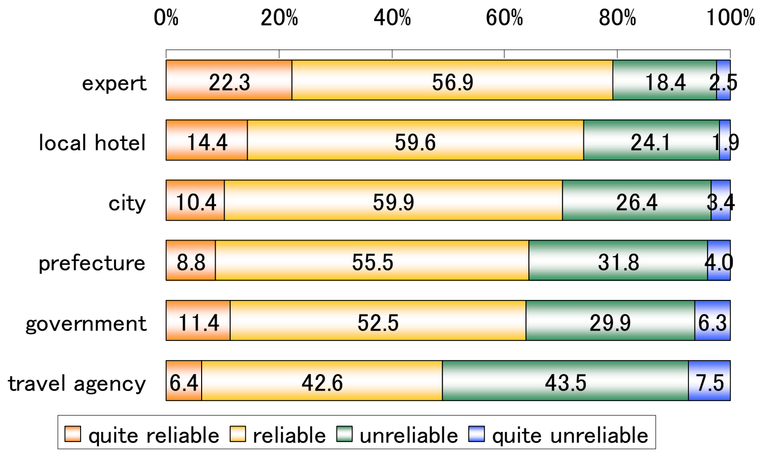

Figure 7: Reliability as source of information

For answers to this question, we were able to see different trends between genders (Figure 8). Focusing on the comparison of men and women, the answers are combined into two: "reliable" and "unreliable". For all sources, women considered them reliable more than men.

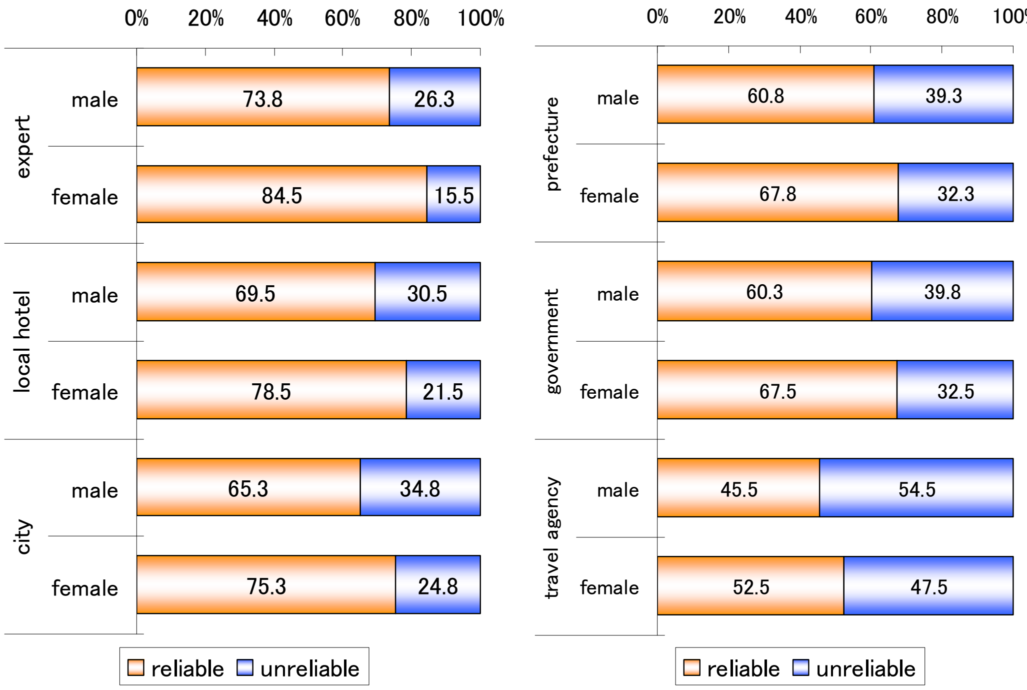

Figure 8: Reliability as source of information by genders

3.5 Usual tourism activity

To the question "how much do you think the effect of these responses (volunteer activity and usual tourism) supports the tourist spots harmed by holding back tourism?", usual tourism was considered as support as well as volunteer activities in the spot (Figure 9).

Moreover, when surveying experiences of help for these tourist spots, there were 18 people with experiences, 3 of whom were involved in volunteer activities and 15 of whom did usual tourist activities. Among the people whose level of awareness is high enough to act, their help correspond to the need of tourists spots.

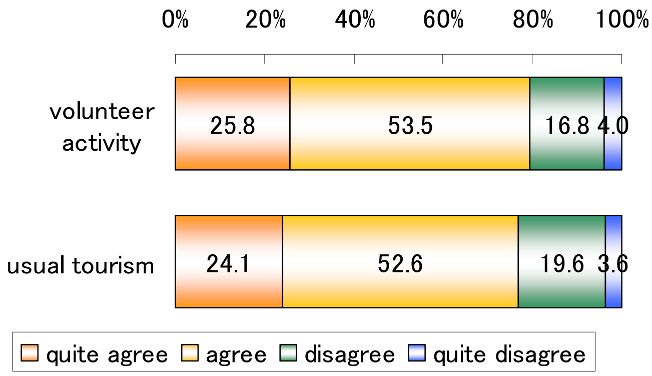

Figure 9: Recognition about support activity

4. PROPOSAL OF COUNTERMEASURE

Preparation of emergency response considering the tourism industry is inadequate. For example, in regional disaster prevention plans there is no independent heading about emergency response for tourism. For holding back tourism in particular, only "damage control" is mentioned and specific measures are not referred to. Therefore, we propose the following measures based on the above results.

From 3.2, it was shown that the main cause of holding back tourism is the recognition of “it seems dangerous”, even without confirmation of the actual damage situation. To this cause, information that regions are “not dangerous = safe” is needed. However, we can say from Section 2.2 that safety information was provided for people inside prefecture but was inadequate for outside people. However, safety information should be provided particularly for people outside of the prefecture because the decrease rate of tourists from outside of prefecture was higher than that from inside as seen in Section 2.3. When considering information provision, we need to keep in mind that women tend to trust information and get image of danger without checking the real situation more than men, as discussed in Section 3.4. In addition, the source of this information should be organization close to the specific region and disaster response experts. For people who already planned tourism to the area, it would be effective to disseminate information actively by local hotel association and municipal organizations. On the other hand, for the potential tourists, it is important to report widely by mass media and to indicate the source of information clearly.

According to Ide (2006), in this highly information-oriented modern society, "information not from the suppliers of tourism, but from whom once has been the same spot would be important." Also, "it would be necessary to rewrite the information by tourists." However, among measures discussed in this study, post-disaster information from local “supplier of tourism” is important because local conditions vary dramatically by the occurrence of disasters. After tourists begin to enter, it is important to create a mechanism to provide information through the eyes of tourists who visited the region after a disaster. Moreover, it was found that most tourists are aware that usual travel would support for the regions suffering from holding back tourism. However, they cannot confirm that they can go to the region because information is inadequate. Therefore, from this aspect, it is essential to inform safety of region.

These proposals are arranged in Figure 10. To the original attraction of tourist spot, after natural disaster, there would be negative (-) element such as "seems dangerous" or "restraint" and positive (+) elements such as "tourism for support" and "curiosity". It is important to provide information that “not dangerous = safety” because the main negative element is "seems dangerous". Also, to spread tourism for support is important. For both measures, information on clearly defined conditions is essential from local institutions and experts. In addition, "tourism for support" should be promoted to convey the needs of the local sights.

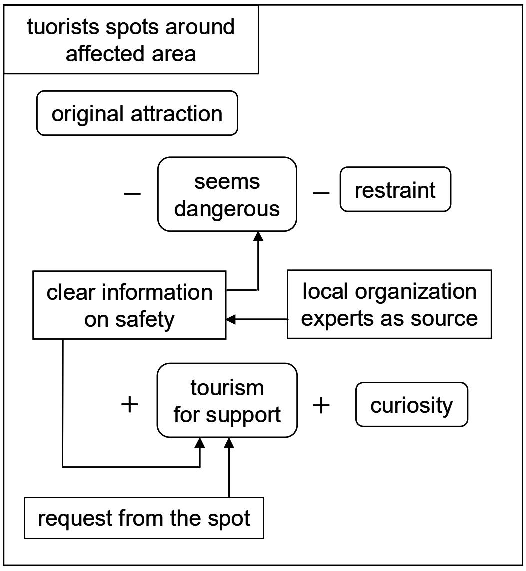

Figure 10: Proposal concept

5. CONCLUSION

Through a case study including newspaper reports and opinion poll, we clarified the cause of holding back tourism. We then proposed countermeasures to build concrete methods to clearly inform safety and to spread tourism for support. However, it is difficult at present to evaluate damage caused by holding back tourism quantitatively. Thus, it is the next challenge to develop techniques to evaluate damage and to verify the effectiveness of the measures we proposed.

ACKNOWLEDGEMENT

Finally, we really thank to those who answered to our questionnaire despite the busy schedule.

REFERENCES

Akira IDE, 2006. Categorization and Future Direction of Recoveries by Tourism. *Proceedings of Institute of Social Safety Science* 19, 91-94

Naoya SEKIYA, 2003. Social Psychology of "Image Contamination" -The Fact of "Image Contamination" and its Mechanism-. *Journal of Japan Society for Natural Disaster Science* 1, 78-89

Cabinet Office: A Summary of Iwate-Miyaga Inland Earthquake
Website: http://www.bousai.go.jp/kinkyu/iwate2/2008-iwate-cao-033.pdf

Kikuzo 2 Visual, Website: http://database.asahi.com/library2/

Iwate tourism statistics (2008),
Website: http://www.iwatetabi.jp/page/association/statistics2009.html

Japan Tourism Agency, 2009. A Report of tourism statistics (2008), 9

Phuket Reconstruction Committee,
Website: http://www.phuketja.org/fukko/tokei.htm

Yoshio KUMAGAI, Yusuke ONO, Takao NAKANO, 1998. An Analysis of Emergency Measures for Natural Disaster in Tourist Cities : Case Study of Municipalities around the Tokyo Metropolitan Region. *Journal of Institute of Social Safety Science* 8, 414-419

Akira IDE, 2006. The Desirable Direction of Future Tourism Information System. *Journal of Information Processing Society of Japan* 128, 99-106

The possibility of involving local wisdom to mitigate substructure construction system concerning Earthquake hazard

(Yogyakarta May 27, 2006 Earthquake case studies)

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ABSTRACT

Mitigation of upper structure construction have been developed dramatically, however only few experts interested with sub-structure's safety, especially for simple buildings. As a part of building which is not only supported upper part of building load, but also should pass that load to the soil underneath besides keep on its balance, consideration of sub-structure safety cannot be neglected.
On May27,2006 Yogyakarta Earthquake , more than 400 thousands simple building were inflicted massive damage, some of them caused by melting of its soil support (liquefaction) or soil settlements. Yogyakarta people have a strong cultural heritage, most of their traditional houses designed in considering its relationship with a natural balanced, the use of timber as the primary material helped much them when the vibration of earthquake attack those buildings. Generally the foundation were made of compacted soil, the interesting things is people used a specific wooden pole with a set of heavy board put on its tip as a compaction tool. The compacted soil can reduces some soil failure such as liquefaction , combine with umpak (short natural stone or heavy timber which is place in the base of column) systems which is possible to move in certain direction, can be one of the tool to support sub structure earthquake resistant construction.

Keywords: local wisdom, earthquake hazard, traditional buildings, Joglo, umpak, soil liquefaction.

1. INTRODUCTION

Mitigation to reduce the impact of the earthquake for building construction is largely done and developed, especially for the safety of upper-structure. Unfortunately, attention to the sub-structure is still very small because many people have an opinion that their failure rarely occur or if there was, almost no impact to the human safety. Though this sub-structure system plays an important role in maintaining the stability of buildings on it . If the sub-structures failure's triggered the large damage can be occurred.

On May 27, 2006 earthquakes with 6.3 Mw scale, in Special Region of Yogyakarta which is located in the central of Java island, more than 400 thousand simple buildings were damaged, some of which are caused by the liquefaction and land subsidence.

State of Indonesia consists of many islands and many tribes, each having different cultures, though sometimes influence each others. Some of those cultural traditions is still followed by the local population. One of the areas of thick cultural heritage is Yogyakarta and its surroundings.

In the construction field, the cultural influence policy in determining the type of buildings to be constructed until the time of commencement of construction. This wisdom was inherited by parents orally, and through examples of applications in situ. Even though it's been mostly done custom modifications of construction in ancient times, it turns out the basics are taken in the building are still using the wisdom. As an example of the symmetrical layout of buildings and the open space between buildings and courtyard. In terms of construction can be seen in is always a consensus to discuss steps to be taken to start construction.

Figure 1 Consultation on the field when it comes to commencement of construction

Construction of traditional buildings in Yogyakarta and Java in general, the most widely applied first and is still there, is Joglo construction, which form the framework of the open, with columns that supported the umpak foundation . Some buildings do type development with a commitment to adopt the system of columns and install wall coverings made of wood. Supported by a double layer and the type of connection to the beam above it, the Joglo framework is mostly more withstand earthquakes than masonry buildings with practical columns.

2.THE PHILOSOPHY OF TRADITIONAL HOUSES IN YOGYAKARTA AND CENTRAL JAVA

Construction of traditional buildings in Yogyakarta and central Java, built on the philosophy that considered the regulations in building construction, the building is not only built for residential, but is expected to bring happiness and prosperity for the residents, this philosophy was handed down orally from parents to future generations. Merging elements of the macrocosm and microcosm for a house

starting from the selection of the site, building design, and also the day when constructionmaybegin.
In the selection of the site, there are four conditions that must be followed (Sumintardja, DJ, 1974), firstly, the conditions on the soil , there are two factors to be considered in determining the condition of the ground where the building will be constructed, namely gasik and loh. Gasik means soil ground in the rainy season should be well drained and not muddy or soggy, and during the dry season do not have cracks. Loh means that soil should contain enough water and fertile soil to grow crops, should also be considered that the land does not stink.

Secondly on the environment, provisions must be followed are: jujugan, which means easy access from any direction, close to places of worship, markets, or station, and rejo meaning lies in the prospects for developing regions, and the last shall ayem which means the building is safe and not damage the environment.

Two other provisions are about the layout or the buildings, fences and gates. Javanese beliefs say that the location of buildings on the river or mountain and direction of its orientation greatly affects the lives of residents, as well as the location of the fence gate, gate location selection is based on the distribution of nine sections (figure2), each section affect the inhabitants of the house, for example on the north side, the door on the second section will be many invited guests, but in the ninth section will make its inhabitants into poverty.

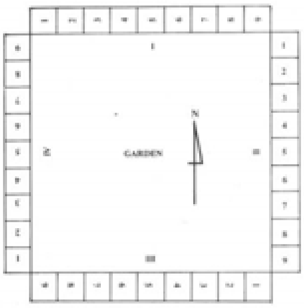

Figure 2 Spatial location of fence gates

Building design is based on the selection form that is joglo roof, the pyramid, the village and grilled, these roof forms essentially determine the floor plan (figure 3). regular building form a square or rectangular.

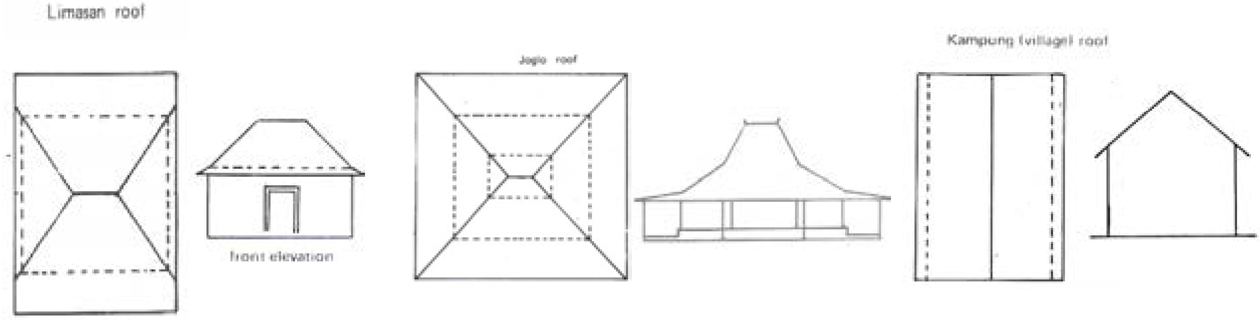

Figure 3 Yogyakarta and Javanese house roof types (source: Sumintardja.Dj)

Building element consists of three parts, the top is the roof and the lid, the middle part consists of sakaguru (middle column), the column edge, and the wall, the bottom consist of foundations, floors and umpak. (figure 4). Umpak as support of the column are located at the foot of columns, the material usually massive stone or old teak wood old enough, umpak is considered as part of the building foundation.

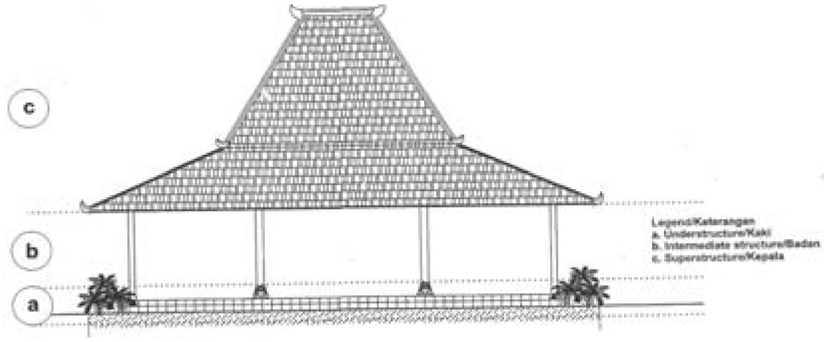

Figure 4 Distribution of types of building elements of traditional Javanese house , a. foundations, floor and umpak, b.column, c. roof and lids (source: Yogyakarta Heritage Society)

Components of the main building is of wood: teak (Tectona grandis), wood jackfruit (Artocarpus heterophyluss), glugu (Cocos nucifera), sengon (albizzia sp) or meranti (Shorea leprosila). Wood used as a column installed in accordance with the direction of wood growth, the top of the tree represents the top of the column, so too the bottom of the timber is the bottom of the column. Wood used is that has no connection intact..

3. TYPICAL FOUNDATION

The part that considered the traditional building foundation is umpak, floor and sub grade construction. Sub grade material is often a mixture of soil and sand, sand usually used is in situ sand, because of the geological conditions, volcanic sand covering almost the entire city of Yogyakarta (figure 5). Before construction foundation system started, the soil compacted manually with a tamping, it is wooden pole whose bottom connected by a thick and heavy board (figure 6). On soft ground were scattered fragments of red brick (gambar7), some even use a brick building intact (figure 8) put under construction umpak -column (figure 9).

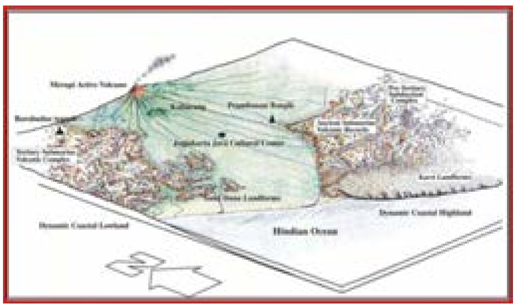

Figure 5 Physiographical conditions of Yogyakarta city and sourrounds (Source: Geological Engineering, Gadjah Mada University, Yogyakarta)

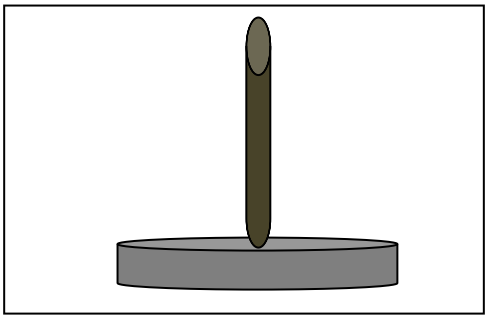

Figure 6 Sketch of tool manual soil compactor

Figure 7 Fractions of red brick as soil stabilization

Figure 8 The composition of red brick below the foundation

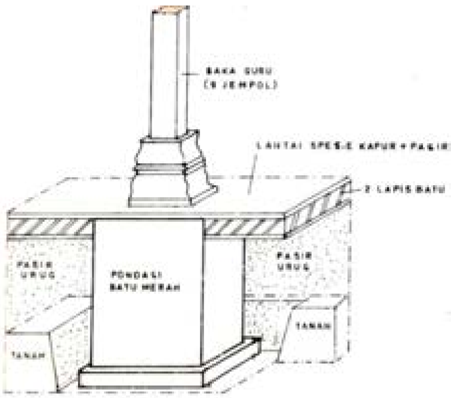

Figure 9 Sketch base of umpak column (source: Public Works Directorate.General)

There are two system construction of columns to the foundation: the first one is hinge support system, column placed on umpak and put on the ground that has been stabilized without any bond, which is relied upon umpak mass weight, the joint between the columns and umpak using tongue and groove system, there is no definitely provision of the length of tongue and groove (figure 10). Saka guru umpak (center) has a dimension greater than the saka rawa umpak (under the column edge) as shown in Figure 11, this system provides an opportunity to column to move in a limited particular direction. The second system is a semi-fix support, called ceblokan system, column is directly inserted into the soil, this column ends smear with tir and wrapped the rope fibers to prevent dry rot (figure 12).

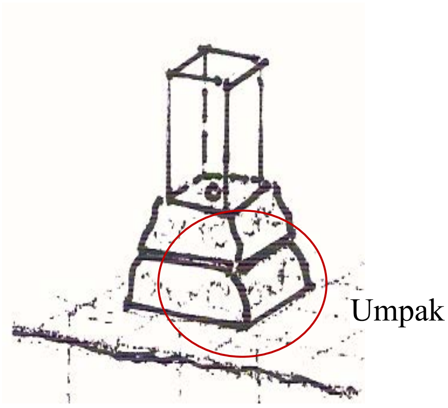

Figure 10 Construction of the umpak column

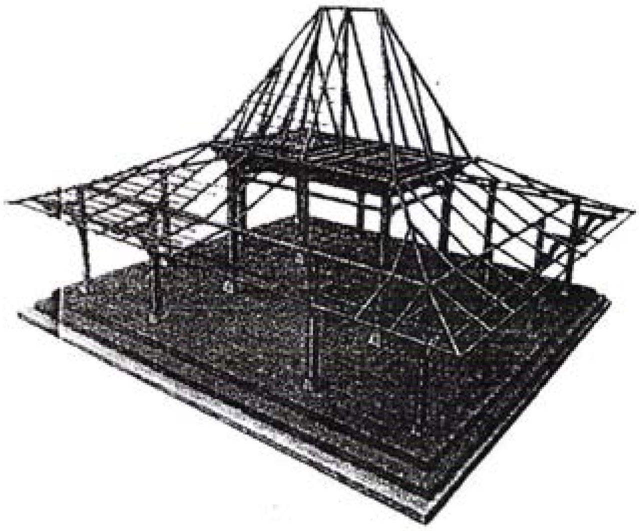

Figure 11, Saka guru umpak in the center of the building, saka rawa umpak at the edge (source image: Prihatmani, JP)

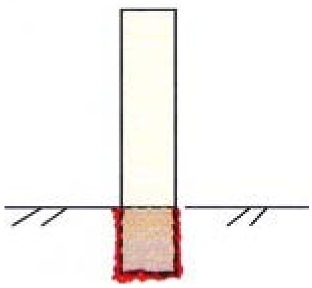

Figure 12, System ceblokan column

Currently, preservation of old buildings anchored umpak and the foundation underneath it, stabilization of soil with broken brick is rarely done, the popular foundation system is the river stone foundation whose made continuous around the building.

4. SIMPLE BUILDING CONDITION AFTER 2006 YOGYAKARTA EARTHQUAKE

In some parts of the city of Yogyakarta and its surroundings show the occurrence of liquefaction, figure 13 below shows the sand boil on one of the wells owned by residents.

Figure 13 Sand boil, in a home residents, the city of Yogyakarta

Liquefaction was also shown by the appearance of sand and soil settlements in urban areas, as in the picture below:

Figure 14 Impact of liquefaction on the building, the city of Yogyakarta

Masonry building without columns have heavy structural damaged, but the structure did not experience in soil settlements or foundation failure, some part underneath of the building stabilized by broken stones, this building is located at 500 m from the Opak river.

Figure 15 Damage to the house in Bantul, 500m near Opak river

On the adjacent site, timber framed building construction suffered less damage than masonry buildings. Figure 16 below shows one of the wooden columns that experienced in a slight shear, while the other columns there is no damage, the location of this building in jl.Adi Sucipto, close to the airport Adi Sucipto who its some buildings suffered severe damage.

Figure 16 Meeting Room, Agency of Research and Development, Ministry of Public Works Yogyakarta

Figure 17 The columns on umpak base

Construction of the Joglo building meeting room at the Sultan Palace still stand up well when the earthquake struck Yogyakarta. Building form which is as a single rigid unit seems quite possible to resist lateral forces caused of earthquake..

Figure 18 The four columns supporting the Joglo building in the palace of Yogyakarta

Figure 19 Construction of a fairly stiff tongue connection of beam of the Joglo building

The failure of the columns of buildings due to lateral forces do not shift the location of the umpak, possibly due to less rigid connection between the connection of the tongue groove in the beam.

Figure 20 System Joglo the sloping frame building because of earthquake force

Cineas, Garin Nugroho homes in the area Jagalan, Yogyakarta, central part Joglo appeared intact after the earthquake, in addition to building houses suffered cracks in the columns and walls. Some wooden column house at Kota Gede also still beautiful stand when there was an earthquake in Yogyakarta, May 27, 2006


a.


b.

Figure 21 a.Joglo's home Garin Nugroho, was not disturbed and b. one of the buildings at Kota Gede , no damage during the earthquake Yogyakarta May 27, 2006

5. CONCLUSIONS

Some local wisdom regarding the design and implementation based on the construction of local cultural traditions can be appointed as the basis of construction, soil compaction tradition of doing before using it in fact is an effort to increase the density of the soil to obtain soil stability, especially if the soil liquefaction potential in the shallow surface. Beam and column construction system which is a single rigid unit, and the use of wooden column umpak system is one way to absorb the energy due to lateral forces. Safety of the building structure below can be enhanced by tie umpak and foundation with an anchor that will spreading concentrated loads from column to the graoun beneath. Deeper study is needed to understand the limiting balance of the gravitational force acting on the column – umpak and lateral earthquake load expected.

REFERENCES

Arsitektur Research Center, Gaja Mada University, 1971. *Studi Perumahan Tradisionil di Yogyakarta dan Sekitarnya.* Direktorat Jenderal Cipta Karya, Ministry of Public Works and Electric Power, Bandung.

Prihatmaji,Y.P, 2003. *Perilaku Rumah Tradisional Jawa Terhadap Gempa.* Thesis, Magister Arsitektur, Institut Teknologi Bandung

Sumintardja, DJ. *Traditional Housing in Indonesia, Central Java.* Masalah Bangunan, Vol 19, No 2-June 1974, pp 32-38. Ministry of Public Works and Electric Power, Bandung.

Yogya Heritage Society, 2007. *Revitalization of Kotagede Heritage District : Homeowner's Conservation Manual.* UNESCO Bangkok, UNESCO Jakarta.

ANALYZING COASTAL COMMUNITY RESILIENCE TO EARTHQUAKE-TSUNAMIS WITH FOCUS ON ARRANGEMENT OF EVACUATION ROUTE AND SHELTER BUILDING

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ABSTRACT

This paper is a report on the study of coastal community resilience in Cilacap. Cilacap is one among small numbers of regency in Indonesia, the first in Central Java, which has disaster management office established in accordance to Indonesia's Law Number 24 of 2007 on Disaster Mitigation. The earthquake with magnitude M7.2 happened in southern Java followed by the tsunami on July 17, 2006 caused some casualties in the area of Cilacap.

TUNAMI modeling was used to produce the wave run-up and inundation map. The input data used for the modeling was bathymetry and topography based on the GEBCO and SRTM 90 m respectively, combining with field survey data. Field survey consists of the bathymetry survey covering around 60 kilometer squares of Cilacap's coastal water and ground check survey. We used hypothetically earthquake scenarios that possibly generating tsunami in the future with several magnitudes, i.e. 7.5, 8.0, and 8.5 Ms scales respectively.

The result of the modeling shows that tsunami run-up will reach the land area with maximum flow depth of 3,8 meters and the inundation will cover 0,5～2.2 kilometers from coastline. For the decision of evacuation route and safe area as well as shelter building, the magnitude of 8.5 Ms will be used as the standard of planning. The choice of the magnitude needs to be considered; by referring that many buildings and infrastructure damaged by earthquake with magnitude lower than 8 Ms. Padang's earthquake, which happened in September 2009 for instance, shows that approximately one-third of the allocated shelters for tsunami evacuation risk were damaged.

1. INTRODUCTION

During the period of the last 45 years, in Indonesia tsunami occurred 20 times or in average tsunami occurs every 2.25 years. The tsunami of Sumatera, which is claimed to be the most casualties in the Province of

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Aceh Darussalam and North Sumatra in December 2004, has been followed by some other tsunami events, namely Nias in 2005, South Java in 2006, Bengkulu in 2007, and Manokwari-Papua in 2008. During the period mentioned above, the tsunami disaster caused more than 250 thousand people dead or missing and property loss of more than 45 trillion rupiah.

In accordance with efforts to reduce tsunami impact, since 2006 Indonesian government (through several relevant government agencies and international aid), has been developing Indonesia's Tsunami Early Warning System (INA–TEWS) to enhance preparedness from tsunami. One effort to improve preparedness is the availability of data predictions on: tsunami travel time from the source, wave height around the coastline, and area of tsunami inundation. With the data availability, hopefully communities and government are going to be able to create a rescue and evacuation scenario by considering the threat of tsunami.

This paper is an interim report on the study of coastal community resilience to earthquake-tsunami. This study is a part of the on-going research to provide tool at local level in assessing resilience of community, particularly in a pilot community of coastal area prone to earthquake-tsunami disaster. In general, the aim of the study was to develop a reference tool or guideline to reduce risks of disaster in selected communities to be adopted in any other vulnerable area to earthquake-tsunamis.

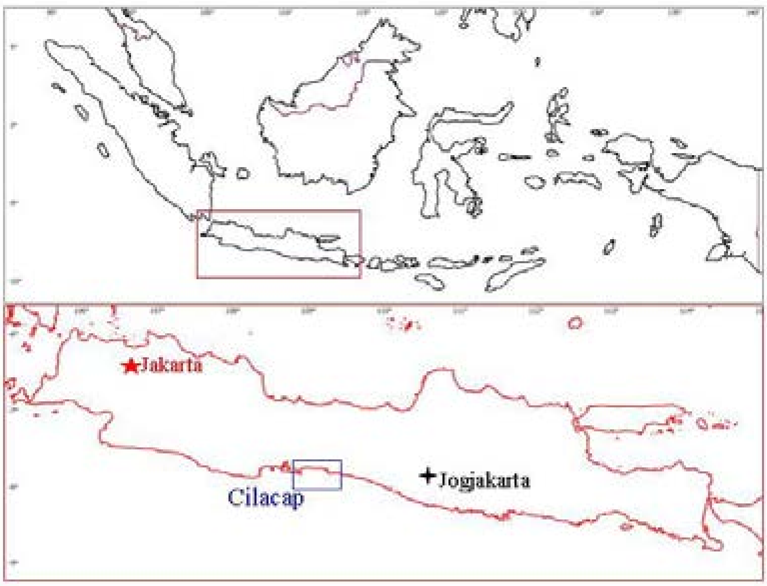

Figure 1 Map of Indonesia and location of the study area of Cilacap Regency

2. METHODOLOGY AND APPROACHES

The study was divided into two stages. The first step was public perception survey and physical environment survey. During public perception survey, questionnaires were distributed, followed by depth interviews, wherein workshops and focus group discussion (FGD), as well as consultation with local government were conducted to investigate and confirm the data collected from questionnaires and depth interviews. Meanwhile, physical survey was done by collecting physical data field, including topography, bathymetry, and tidal measurements. Physical field data were collected for the purpose of developing numerical modeling of tsunamis. In this study, numerical model was developed based on the earthquake-tsunami potential without considering other coastal disasters. The second step of the study was constructed to select evacuation route and safe areas, including potential areas to build shelters, based on numerical modeling and the results of public perception survey.

2.1 Study area

Cilacap Regency was selected as a pilot study area based on the data availability, strategic value consideration in term of business and industrial activities of the region, willingness of local government and communities to collaborate with, and ease of access. Besides, Cilacap Regency is the first regency in Central Java that has been implementing the Law No.24/2007 by the establishment of the Regional Disaster Management Office. The new Law No.24/2007 on Disaster Management has been legalized to response to policy on disaster risk reduction and preparedness in Indonesia. Figure 1 shows the location of the study area.

Cilacap Regency is an area with approximately 2138 km^2 and considered to be the widest regency in Central Java province. The regency is inhabited by 1,727,607 population spread in 23 sub-districts. Among 23 sub-districts, 11 sub-districts have a coastline immediately adjacent to the Indian Ocean. In general, the coastal area of Cilacap has flat topography with a height less than 8m up to 5 km distance from the coastline. Based on data from the last 30 years (1977-2007), a total of 420 earthquakes struck the region with the epicenter at a depth of less than 40 km with a magnitude>5.0 Mw. During those periods, it was recorded at least two tsunami events, the tsunami Banyuwangi in1994 and South Java tsunami in 2006. The event of the tsunami on July 17, 2006 caused 165 people died and a few dozen were wounded and missing in Cilacap Regency (Wibisono, 2008). The number of casualties was mainly caused by the tsunami waves. Based on field measurements after the tsunami, it was noted that the depth of water *(flow-depth)* ranges from 1 to 5 meter with the increase of water *(run-ups)* ranges from 3.6 to 5.4 meter, and the water reaching to the mainland *(inundation)* was 450 meter from shoreline in some villages (Cousins *et al.*, 2006; Kongko *et al.*, 2006; Lavigne *et al.*, 2007).

2.2 Coastal Community Resilience (CCR) Framework

There are several methods to measure the resilience of coastal communities, including the establishment of existing conditions of vulnerability of a region based on social systems, natural conditions, and built environment (Cutter, 2006), by assessing and determining the coastal vulnerability index globally (UNEP, 2005). In collaboration with the countries in Indian Ocean region, under cooperation program in the framework of the Indian Ocean Tsunami Early Warning System (IOTEWS), USAID has issued a guidance for evaluating coastal community resilience to tsunamis and other coastal disasters (earthquakes, storms, erosion, sedimentation, oil spills, sea level rise, destruction of coastal resources, etc.) that has been collected in a package of Coastal Community Resilience/ CCR

(USAID, 2007). In this study, the CCR-IOTEWS framework was used as a reference.

Coastal Community Resilience (CCR) is defined as the ability to receive the impact of coastal disasters (such as tsunamis, floods, storms, coastal erosion or coastal hazard), to be revived from the event of disaster, and to adapt to ongoing changes in circumstances. Resilience is an integration and balance of three frameworks that is Community Development, Coastal Management, and Disaster Management, in which the implementation of the programs is based on community-based planning. Community Development framework enables resilience for socio-economic conditions and culture. Coastal Management framework is intended to create an environment and natural resources resilience. Meanwhile, Disaster Management framework focuses on preparedness, response, recovery and mitigation to reduce casualties and loss of property and infrastructure from disaster.

Since the CCR-IOTEWS concept covers a very broad aspect to measure the elements of community resilience, particularly in the questionnaire survey, in this study modifications of the methods and scoring were done. Modifications were made primarily by giving the score number on the answer choices, while the original document score value given by the surveyor. The scores were in the range of 0, 1, 2, 3 and 4 representing the lowest to the highest response. The score was [0] Not know / No / Not ever; [1] Little/ Poor/ Not There; [2] Enough/ Few/ Moderate; [3] Good/ Many/ Large; and [4] Very good/ Very much/ Very big. List of questions were selected and arranged to meet local needs. This modified method was assumed to be more objective to reveal the real conditions in the field, and to avoid or at least to reduce the subjectivity of the surveyor. To maintain consistency and uniformity among surveyors related to data collection method, at the initial stage calibration was done by executing survey in one location together.

2.3 Tsunami modeling and map development

The purpose of modeling is to simulate the tsunami wave from generation, propagation, and inundation to know the characteristics and behavior of the tsunami. Tsunami model used in this study was only generated by the movement of the seabed by the earthquake. To simulate the propagation of tsunami waves, two-dimensional hydrodynamic model of linear long wave equations of motion was used. While for simulating the tsunami run-up, the theory of nonlinear shallow water was used. Tsunami modeling was done using TUNAMI N3 (for near-field tsunami) developed by Tohoku University of Japan. Numerical equations were developed using Non-linear shallow water equation (NSWE), i.e. long-wave hydrodynamics equations with the numerical solution using finite difference method (FDM) and Leap Frog scheme, based on input parameters of seismic, bathymetry and topography. The output of the simulation was information about the wave height, run up height, travelling times of waves from sources to the coast of Cilacap. The data resulted from modeling were then presented in the form of forecasting inundation map as well as hazard map.

3. FIELD OBSERVATIONS AND MODELING

3.1 Measurement of community resilience elements in the field

To identify the community resilience to coastal disasters in Cilacap Regency, parameters of resilience were measured during the initial step. Research locations were spread on 4 villages in 4 sub-districts in Cilacap Regency. The locations were chosen by considering that the areas had largest number of casualties and damage in Cilacap Regency when the areas were attacked by the tsunami of July 17, 2006. In each village 100 copies of questionnaires with a total of 85 questions divided into 8 elements/ groups were distributed. The resilience elements measured in the survey include: [1)] Governance, [2] Social-economy and livelihoods, [3] Coastal resources management, [4)] Land use and structural design, [5] Risk knowledge, [6)] Warning and evacuation, [7] Emergency response, and [8] Disaster recovery.

Based on the CCR-IOTEWS standard, value 2 (two) is set as the limit of minimum value (threshold) to measure the resilience of a region. As a consequence, if there was an element with average scores less than two (<2), it was then avowed as low-resilience. In this study, to assess the resilience of coastal communities in Cilacap Regency, a standard score (benchmark score) was used as follows: [4] Very Good; [3] Good; [2] Fair; [1] Bad; and [0] None. The result of resilience measurement in the survey areas is shown by spider-graph to easily recognize the level of resilience. Field study has been conducted during the period March to April 2009. Workshops and FGD were conducted in August 2009. Moreover, the physical survey and field observations has been previously conducted between the periods of July 2006 until August 2008, and then continued in August 2009.

3.2 Model tsunami and *Set-up* model

The Southern Java tsunami of July 17, 2006 was not the only benchmark to identify the risks of tsunami in Cilacap Regency. The simulation to determine the potential run-up, flow-depth, and the potential inundation were conducted based on the magnitude and epicenter as a source which allows tsunami generating (hypothetical sources). In this regard, finer topography and bathymetry data were needed to develop numerical modeling of tsunami at local scale. In addition, the validated source/ tsunami scenario was also needed. Earthquake parameters data (depth, the length and width of the earthquake, the angle of the strike, dip, slip and dislocation) were obtained from the USGS website (United States Geological Survey). The bathymetric and topographic data were obtained by combining primary and secondary data.

Bathymetric and Topographic Data

Bathymetric and topographic data used were GEBCO *(General Bathymetric Chart of the Ocean)* and SRTM *(Shuttle Radar Topography Mission)* coupled with topographic and bathymetric measurement data at the local scale obtained within the framework of Indonesian-German cooperation projects namely German-Indonesian Tsunami Early Warning System (GITEWS), which produce data with better resolution.

Bathymetric data for modeling was based on ocean depth map GEBCO with 1-minute resolution level (1850 meters) plus a special depth measurement in coastal water areas (near shore bathymetric) using Multi-beam instrument survey. Whereas the coastal topographic data were used with SRTM-90 m with the corrections based on ground surveys (ground check) by leveling every 100 meters along the study area of Cilacap by width 200 meters to inland from coastline. By measuring bathymetry of coastal water and topography correction, it was expected that the input data for modeling would be closer to actual conditions in the field.

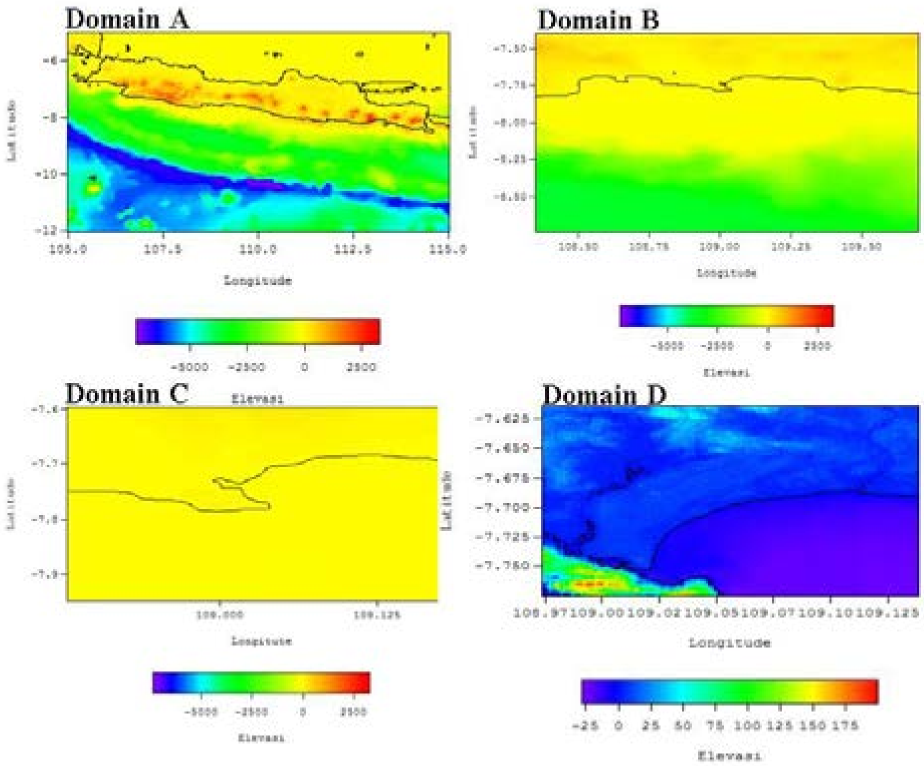

Figure 2 Setting-up of domain area for TUNAMI modeling in Cilacap Regency

<u>Designation of Study Area (Domain)</u>

Considering the modeling which covers a wide area, ranging from seismic source, tsunami generating sources until the run-up area, with considerations of time consuming in running the model, a nested grid system was used. For the purpose of numerical within this nested grid system, the domain used in the modeling was divided into four domain units namely domain A, B, C, and D. Domain A was the largest domain in the area between $105^{\mathbf{o}}$ to 121^{o} longitude and -5^{o} to -12^{o} latitude. Domain B was the area within the domain A with the boundaries of 108^{o} 21’ 00”to 109^{o} 42’ 00” longitude, and 8^{o} 43’ 60” to 24^{o} 00’ 00.2” latitude. Domain C was the area within the domain B with the boundaries of 108^{o} 52’ 44” to 109^{o} 11’ 15.4” longitude, and 7^{o} 56’ 43.4” to 7^{o} 35’ 53.9” latitude. Domain D was the area within the domain C with the boundaries of 108^{o} 58’ 28.6” to

109° 08’ 16.1” longitude, and 7° 46’ 26” to 7° 36’ 52.2” latitude. Figure 2 shows the setting up of domain areas for this study.

In this model, Manning coefficient was set-up as 0.025, by assuming that all surface roughness was uniform. Hypothetically earthquake scenarios that possibly generating tsunami in the future with several magnitudes, i.e. 7.5, 8.0, and 8.5 Ms scales respectively were used. The running time of the model was determined as 3 hours (10.800 seconds). Inundation map, ideally, made of some tsunami scenarios that might occur; was developed by doing a superposition of each scenario on each segment of the study area.

4. RESULTS AND DISCUSSION

Figure 3 shows the map of inundation areas based on the simulation of tsunami (hypothetical tsunami) with the scenario as described in Section 3. 2. For a better appearance, hence the simulation results in over-lay using Google Earth imagery. From the map it is shown that the scope of inundated area is wider compared with previous study (Mardiatno *et al*., 2008).

Figure 3 Inundation of study area with three earthquake scenarios, M7.5, M8.0, and M.8.5 which then over-layed by Google earth images

Explanation of this is as follows: First, the scenario of the tsunami sources is different so the rupture parameters as tsunami’s generating sources also differ. Second, another significant difference is the level of finer resolution bathymetric and topographic data for input modeling. The result of the modeling shows that tsunami run-up reaches the land area with maximum flow depth 3,8 meters and the inundation covers 0,5～2.2 kilometers from coastline to inland. The simulation result also shows that South Cilacap sub-district (Tegal Kamulyan Village) is potential as the region with highest risk level compared to other regions. These results are consistent compared to previous research (Wibisono, 2008; Mardiatno *et al*., 2008). The travel time of the first wave reaches the shoreline of Cilacap was 36 minutes, based on the observation point on the tidal station at the port of Cilacap. The results of the modeling coupled with data on post- South Java tsunami in 2006 field survey were used as a reference to choose the location of the questionnaire survey, and to determine safe area and evacuation route.

4.1 Element of Warning and Evacuation

Community perception through questionnaire survey and interview was needed to get information to determine how far the level of community preparedness to face the danger of next tsunami event. From the field work, it is shown that the average resilience rate of all eight elements was less than two, which is categorized as below the critical limit of resiliency. This character was also nearly uniform for all measured elements (Hidayat and Meguro, 2010). To further know the public perception regarding evacuation routes and shelter building, it is shown in element no. [4] Land-use and Structural Design and [6] Warning and Evacuation. Figure 4 shows in detail one example of public perception measurement results based on following questions: Q1. To what extent does the community know about the need for an evacuation route? Q2. To what extent has an evacuation route been socialized to the community in your area? Q3. To what extent have there been evacuation simulations undertaken by the community in your area? Q4. Is there an agreed system for socializing the early warning and evacuation plan in your village? and, Q5. To what extent does the evacuation plan involve all members of the community in your area? From the graph, it is clear that the majority of the respondents (>70%) gave answers to the five questions with “Not yet, Very Little, Little”, showing that the level of community preparedness is still low.

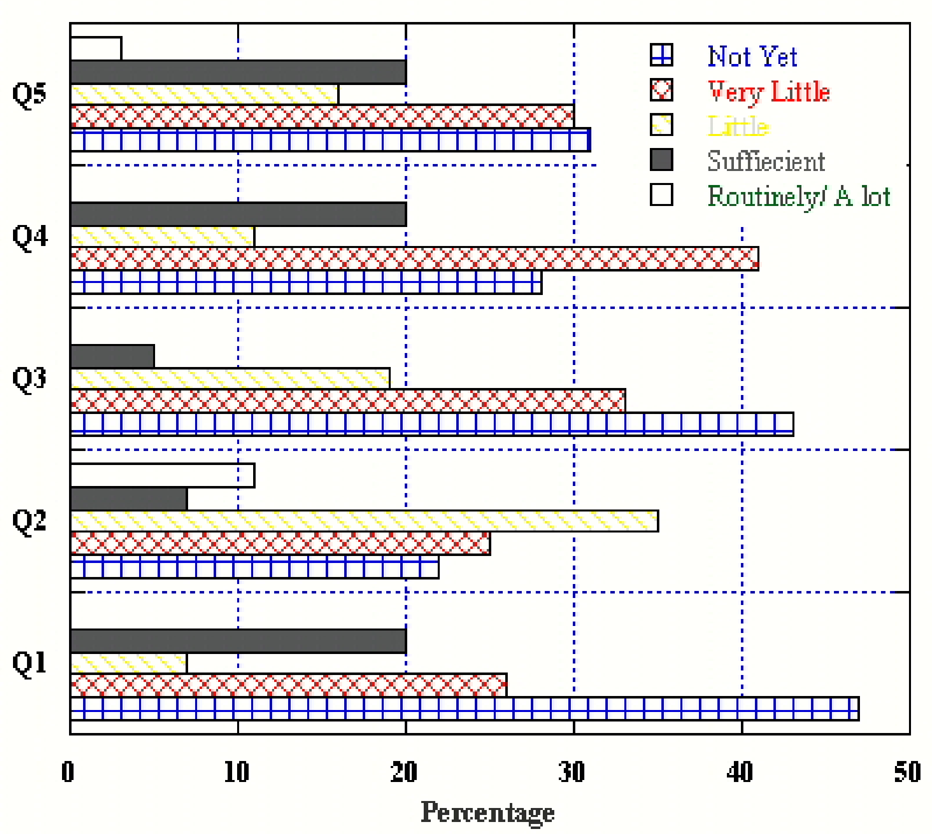

Figure 4 Warning and evacuation elements of CCR based on questionnaire survey in Cilacap

4.2. Consideration in Designation of Evacuation Route and Shelter Building

Knowing the estimated time for arrival of a tsunami and the time needed for evacuation is essential for evacuation planning. In Cilacap, it was assumed that the first wave would reach coastal line in 36 minutes after earthquake. Inundation map (tsunami inundation forecast map) was analyzed to determine tsunami hazard map. Evacuation route and safe area including the area to build shelter were then determined based on tsunami hazard map. Based on the hazard map, an evacuation capability of the population was assessed.

Figure 5 Potential locations for evacuation roads and safe area/shelter building in Cilacap [source: Wibisono (2008), with modification]

The basic principle of the approach was to calculate the time needed to evacuate to the nearest evacuation building, taking into account the parameters that effect on people's evacuation speed. A flat road, for example, allows faster evacuation speed than dense vegetation or paddy field. The analysis made here was based on limited spatial data only, so the assessment rely more on direct observation in the field. Field observation was used to identify the conditions of the building, roads including bridges, both within potentially inundated and surrounding areas. Referring to the Tsunami Mitigation Guidelines for Evacuation Buildings Book (Anonymous, 2005) it is noted that there are two options for the determination of tsunami evacuation building/ shelter, i.e. to use existing facilities or new construction. Based on our finding during field observation, we proposed some locations as a safe area (horizontal evacuation) and a small number of buildings for vertical evacuation, as shown in Figure 5.

Special attention is needed to be considered on the selection of existing facilities as a designation of evacuation routes and shelter building. Experience in many seismic events in Indonesia, for example the earthquake in Aceh in 2004, Yogyakarta in 2006, and Padang in 2009 showed that many reinforced concrete buildings collapsed due to structural failures. Recently Padang's earthquake on September 2009 shows that approximately one-third of the allocated shelters for tsunami evacuation risk were damaged. In addition, some roads were covered with ruins of collapsed buildings as well as roads damaged, so it did not allow to be used as an evacuation route, even if the path was already established as the tsunami evacuation route for dealing with future tsunami event (Sigit *et al.* 2010). For the study area of Cilacap, it was not found yet examples of earthquakes which destroyed reinforced concrete buildings, as mentioned above. However, when referring to the Seismic Hazard Map of Indonesia (SNI-03-1726-2002), it is mentioned that maximum Peak Ground Acceleration (PGA) at bedrock (for 10% in 50 years) for each location is as follows: 0.15g in Yogyakarta, Padang 0.30g, and Aceh between 0.2 and 0:25g, and Cilacap 0.20g. This indicates that the potential hazard in Cilacap is as equal as in Aceh and greater than the potential hazard of Yogyakarta.

5. CONCLUSIONS

Although tsunamis happen quite frequently in Indonesia, most people living in the risk areas have never experienced a tsunami during their lifetime. To improve preparedness, risk maps, evacuation plans, and shelter building are needed. The production of this reference is not able to be delegated to the entire communities because necessary knowledge may not be sufficient locally. Support from experienced experts and scientist are needed. Having an evacuation plan in place when a tsunami warning comes is crucial for effective preparedness and quick reaction. Evacuation planning is the task of local authorities.

A numerical simulation is very helpful in the efforts to mitigate coastal area from tsunami disasters, particularly in the areas where only insufficient records of tsunami inundation in the past are available. However, it is necessary to design a numerical simulation carefully to obtain reliable results, particularly to set-up input data and tsunami's generating scenario. With the assistance of the modeling the affected areas of risk (including wave's arrival time, wave height, run-up and flow depth in coastal area, and the penetration of the wave) can be predicted more accurately in each location. However, this supporting instrument might be more credible if it is supported by accurate data entry and verified by field data.

INA-TEWS is designed with clear vision of national and local level. However, it is considerably known that at the moment, many local governments are not aware of their roles within INA-TEWS.

REFERENCES

-----------, 2005, Tsunami Mitigation Guidelines for Evacuation Buildings, Review Committee on Tsunami Mitigation Guidelines for Evacuation Buildings, Director General for Disaster Management, Cabinet Office, Japan.

Cousins, W. J.; Power, W. L.; Palmer, N. G.; Reese, S.; Tejakusuma, I.; Nugrahadi, S. 2006. South Java Tsunami of 17th July 2006, Reconnaissance Report, *GNS Science Report* 2006/33 p42.

Hidayat, R., and Meguro, K., 2010, Developing parameter for measuring coastal resilience by using community based perceptions and tsunami run-up modeling, IOC/WESTPAC, E-Bulletin, May 2010, pp 4-6, http://www.unescobkk.org/fileadmin/user_upload/westpac/documents/E-bulletin/E_Bulletin_No_6_May_10.pdf.

Kongko, W., Suranto, Chaeroni, Aprijanto, Zikra, Sujantoko, 2006, Rapid Survey on Tsunami Jawa 17 July 2006. http://ioc3.unesco.org/itic/files/tsunami-java170706_e.pdf.

Lavigne, F., Gomez, C., Giffo. M., Wassmer, P., Hoebreck, C., Mardiatno, D., Priyono, J., and Paris, R., 2007, Field Observations of the 17 July 2006 Tsunami in Java, *Natural Hazards Earth System Sciences*, 7, pp.177-183 (www.nat-hazards-earth-syst-sci.net/7/177/2007/).

Mardiatno, D., Kongko, W., Lavigne, F., Sunarto, and Stoetter, J, 2008, GIS Application for Tsunami Risk Assessment in Cilacap, South Java-Indonesia, *Proc. International Conference on Tsunami Warning (ICTW),* Bali, Indonesia.

Sigit, S., Murakami, K., Rinaldi, 2010, Evaluation of Tsunami Evacuation Risk in Padang City-Case Study on 2009 West Sumatera Earthquake-, Kayou Kaihatsu Rombun-shu, No.26, 2010.

Twig, J., 2007, Characteristics of a Disaster-resilient Community: A Guidance Note, DFID-DRR-ICG, (Bahasa Indonesia version, translated by Theresia Wuryanti).

USAID, 2007, How Resilient Is Your Coastal Community? A Guide for Evaluating Coastal Community Resilience to Tsunamis and Other Hazards; *U.S. IOTWS Document No. 27*-IOTWS-07

UNEP, 2005, Assessing Coastal Vulnerability: Developing a Global Index for Measuring Risk, pp.54, ISBN No: 92-807-2577-7, online version : *http://www.unep.org/DEWA/products/publications/2006/CVI_PM65_Final_05.pdf*

Wibisono, A.A., 2008, Tsunami Mitigation Study with Determination of safe area and the evacuation route in Cilacap Regency, Central Java Province based on Tsunami Run-up simulation model, UG.Thesis, *Dept. of Environmental Engineering, Faculty of Mineral Technology, Pembangunan Nasional "Veteran" University, Jogyakarta* (in Bahasa Indonesia, unpublished).

Modeling the SARS epidemic in China based on dynamical passenger flow in railway and airline networks

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ABSTRACT

This paper presents a framework for the simulation of large-scale spread of epidemics in realistic mobility networks, such as railway, civil aviation and other transport networks. The framework consists of three parts: the population structure model, the dynamical passenger flow model and the local infection dynamics model. The population structure model, which is based on the metapopulation network, depicts the heterogeneity of the distribution of personnel and the way of contact between them. The dynamical passenger flow model, which constitutes the mobility network model and the passenger traveling model, has considered three key features of the passenger traveling patterns in the transportation networks, including the traveling process, waiting process, and returning process. The local infection dynamics model adopts a stochastic SEIR (Susceptible-Exposed-Infected-Recovered) model to describe the mechanism of the spread of infectious diseases in local metapopulations. We have implemented the model framework and the history data of 2003 SARS (Severe Acute Respiratory Syndrome) epidemic in China has been used to compare with the simulation results for verifying the feasibility of our model. Simulation results show that our model can well reproduce the main characteristics of the process of SARS transmission. These results and their analyses can not only be used to generate insights into understanding the dynamic processes of epidemic spreading, but also support the emergency management sectors to make more effective and efficient prevention and control strategy of epidemic spreading.

Keywords: epidemic modeling, traveling patterns, mobility network, SARS

1. INTRODUCTION

The spread of epidemics in human populations is a typical public health incident, and has also become one of the major public safety issues that humanity is facing in the 21st century. Traditional epidemiological research has focused on the use of rate-based differential-equations to establish the mathematical models of the spread of infectious diseases, such as SIR and SIS compartment models (Hethcote, 2000). Although successful in explaining certain phenomena of epidemic spreading, the traditional approach is unable to deal with epidemic spreading in realistic large-scale social contact networks with significant heterogeneity due to its assumption of uniformly mixing populations. Therefore, the approach based on a combination of complex network theory and epidemiology has become an important trend in modeling of transmission of infectious disease.

Meyers et al. (2005) applied the methods of contact network epidemiology to illustrate that for a single value of the basic reproduction number R_0 —the number of new cases of infected individuals resulting from a single initial case, any two outbreaks, even in the same setting, may have very different epidemiological outcomes, which cannot be explained by the traditional compartmental models. Yang et al. (2004) proposed a simple contact network model to study the immunity mechanism of the network during the spreading of SARS: the SARS spreading will destruct the network, and in turn the destructed network can halt the SARS spreading effectively. Watts et al. (2005) introduced a class of metapopulation models in which they assume that local contexts are embedded in a nested hierarchy of successively larger domains and homogeneous mixing holds within these local contexts. The individuals are allowed to move between contexts via simple transport parameters. Their model suggests that when epidemics do occur the basic reproduction number R_0 may bear little relation to their final size, and exhibits some important stylized features of real epidemics, including extreme size variation and temporal heterogeneity, which are all difficult to characterize with traditional compartmental models.

However, previous studies on network-based epidemic models have remained mostly theoretical, practical application-oriented research is relatively few. Moreover, the passenger travel process which is an important factor in globally transmission of the infectious diseases are usually oversimplified due to the lack of quantitative knowledge of human traveling statistics. Recently, Brockmann et al. (2006) analyzed the dispersal of bank notes in the United States and extracted the scaling laws of human travel; i.e., the human travel distance r and the rest time t_w between displacements obey the heavy tailed distributions $p(r) \sim r^{-(1+b)}$ and $p(t_w) \sim t_w^{-(1+a)}$, respectively, where they predicted $a = b \approx 0.6$. Gonzalez et al. (2008) studied the human mobility patterns by analyzing the trajectory of 100,000 anonymized mobile phone users whose position is tracked for a six-month period, and find that the distribution of displacements over all users is well approximated by a truncated power-law: $p(r) = (r + r_0)^{-b} \exp(-r/\kappa)$ with $b = 1.75 \pm 0.15$, and they also find that the traveling individuals have a significant probability to return to a few highly frequented locations. These new findings have greatly help researchers understand how the human mobility patterns affect the virus spread (Colizza and Vespignani, 2007; Ni and Weng, 2009).

In modern life, passengers can do frequently long-distance travel by the railway and civil aviation transportation networks, which are two of most important way of human travel that are responsible for large-scale epidemic spread. Therefore, recent studies on epidemic modeling have paid attention on the role of the railway and civil aviation networks in the spreading of infectious diseases (Hufnagel et al., 2004; Bowen et al., 2006). However, the scaling laws of human mobility mentioned above were still not considered in these studies. In this paper, we proposed a framework for the simulation and analysis of large-scale spread of epidemics in realistic mobility networks, such as railway and civil aviation, in which the passenger travel patterns, including the travel process, waiting process, and returning process have been implemented in detail. We have implemented the model framework and the history data of 2003 SARS (Severe Acute Respiratory Syndrome) epidemic in China has been used to compare with the simulation results for verifying the feasibility of our model. Preliminary simulation results show that our model can well reproduce the main characteristics of the process of SARS transmission.

2. POPULATION STRUCTURE

In our model, the study population consists of 1,211,030,000 people, which is divided into 314 prefecture-level cities located in China's 31 provinces, autonomous regions and municipalities in accordance with the existing administrative divisions. Within each city, the population is further divided into a number of metapopulations (subpopulations that represent communities, schools, workplaces, hospitals, etc.) according to the following metapopulation network algorithm (Ni and Weng, 2009). Consider a city i that has a population of N_i individuals. The population N_i is randomly partitioned into M_i metapopulations $N_{i,j}$ $\left(j=1,2,...,M_i\right)$, each of which is represented by a node of the metapopulation network and the initial size of $N_{i,j}$ is drawn from a power-law distribution $p\left(N_{i,j}\right) \sim N_{i,j}^{-\eta}$ where η is an exponent parameter and $N_{\min} \le N_{i,j} \le N_{\max}$. In this way, these metapopulations (nodes) are connected by a network and individuals in one node can diffuse along the network links to other nodes in their daily travel activities.

In order to incorporate the scaling law of human travel into our model, we define the network substrate on a two-dimensional square space of unitary length on the $x-y$ plane with periodic boundary conditions. Specifically, each node j $\left(j=1,2,...,M_i\right)$ is randomly assigned a pair of values $\left(x_i, y_i\right)$ to represent its coordinates on the geographical plane. We assume that each coordinate is an independent and identically distributed random number drawn within the interval $\left[0.0,1.0\right)$. Initially, m fully connected nodes, labeled by $1,2,...,m$ respectively, are randomly distributed in the square, and then at each time step t $\left(t=m+1,m+2,...,M_i\right)$, a new node labeled by t is added to the network and connected to m preexisting nodes according to the attachment probability that the node j $\left(j=1,2,...,t-1\right)$ would be chosen to connect to the newly added node t:

$$\pi_j\left(t\right) \sim k_j^{\alpha}\left(t\right) / d_{jt}^{\beta} \qquad (1)$$

where d_{jt} is the Euclidean distance between the nodes t and j, which is measured using periodic boundary conditions, and α and β are two tuning parameters governing the degree distribution and link length distribution respectively.

As Ni and Weng (2009) pointed, the resulting network shows two striking features: (i) the network have a skewed degree distribution, which is consistent with the actual situation; (ii) the link length that is defined as the probability that a randomly selected link has the length r follows a power-law distribution $p(r) \sim r^{-(\beta+1)}$ for proper configurations of α and β, which is a convenient feature for modeling the scaling law of travel distance. For more information about the above metapopulation network, please see the reference (Ni and Weng, 2009).

3. THE DYNAMICAL PASSENGER FLOW MODEL

3.1 The Definition of Train and Airline Networks

The main objective of establishing the metapopulation network in the previous section is to simulate the urban travel process because we are lack of specific mobility data of personnel's daily travel within the city. However, in reality, individuals can not only move inside the city, but also move to other cities through the railway and civil aviation transportation networks that connect the cities to each other. Therefore, in this section, we will describe the construction method of the train and airline networks.

The train network is defined as a weighted, directed network based on 4877 train stations and 2622 trains in China. Specifically, each train station is regarded as a node in terms of the network terminology. If there is a train bound for train station j from train station i, then a directed edge e_{ij} from node i to node j will be established. If there are n trains from station i to j, then we will define the value $w_{ij} = n$ as the edge weight for e_{ij}, and the value $s_i = \sum_{i \in \Upsilon(i)} w_{ij}$ will be defined as the node weight for node i, where $\Upsilon(i)$ represents the set of neighboring nodes of node i. In Fig. 1(a), we depict the train network where each node represents one of 314 prefecture-level cities and the edge means there are one or more trains connect these two cities. Here, most of the city node contains more than one train stations while a few of cities have no train stations.

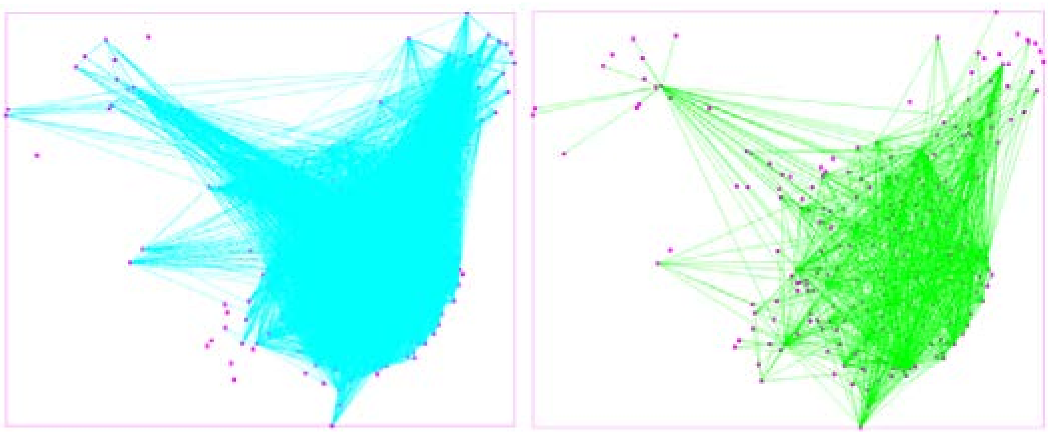

Figure 1: China's train network (a) and civil airline network (b).

The airline network is made up of 134 civil airports and 8299 flights, and the construction method is the same as that of the train network as described above.

Fig. 1(b) shows how the 314 prefecture-level cities in China are connected to each other by the airline network, where the isolated nodes (represent prefecture-level cities) indicate there are none of airports in these cities.

It should be noted that the train network and the airline network load a large portion of long-distance (between 50km~1500km) traffic flow and another part of long-distance (~100km) traffic flow are handled by the inter-city highways and roads, which are not considered by our model for the current study.

3.2 The Passenger Traveling Model

The passengers' daily travel that including the local travel within the city and the global travel between cities is responsible for the large-scale spread of the infectious diseases. However, the actual process of passenger travel is too complex to be directly considered, so that we can only take the simulation method to describe it. Therefore, whether the simulated passenger flow can capture the characteristics of the actual one is critical for the modeling of epidemic spreading. In this paper, we model the passenger traveling process as follows.

(1) *Traveling*.

(1.1) *Choice of travel distance*. For each infected individual h that initially located in node i, at each time step, it will leave the node i with probability $p_{i,travel}$ and then go to step (1.2); otherwise, it will go to step (1.3). The parameter $p_{i,travel}$ is the probability that any individual in city i will travel by train or air, and can be evaluated by the following equation:

$$p_{i,travel} = \frac{d_{eff}}{365} T_i / N_i \qquad (2)$$

where T_i is the annual traffic by train and airline in the city i, N_i is the population size of city i, and d_{eff} is an empirical coefficient.

(1.2) *Global travel*.

(1.2.1) *Choice of transport mode*. The infected individual h will travel through the railway network with probability $p_{i,train}$, and through the civil aviation network with probability $\left(1-p_{i,train}\right)$. The value of $p_{i,train}$ can be determined by Eq. (3):

$$p_{i,train} = T_{i,train} / T_i \qquad (3)$$

where $T_{i,train}$ is the annual traffic by train. If there is no railway station in city i, $p_{i,train}$ will be set to 0. Similarly, if there is no airport in the city, $p_{i,train}$ will be set to 1.

(1.2.2) *Choice of travel route*. Because there are usually multiple railway stations or airports in a prefecture-level city, the infected individual h needs to choose the departure and arrival sites before its traveling. Taking as an example, when the individual choose to travel through the railway network, the selection process of the travel route can be described as follows. Firstly, the individual will select one of railway stations in the city as a departure site with a probability proportional to the node weight of the site. Then, one of edges that emanate from the departure node will be selected as a travel route with a probability proportional to the edge weight. The individual will enter into the city containing the arrival site that is connected by this edge.

(1.2.3) *Choice of target metapopulation*. Finally, the individual will enter into the target metapopulation which is randomly selected from all metapopulations in the arrival city and go to step (2).

(1.3) *Local travel*. The infected individual h will jump into a neighboring metapopulation node with probability $p_{i,jump}$ and go to step (2); otherwise, it will continue to stay in the original metapopulation node. The parameter $p_{i,jump}$ is given by Eq. (4):

$$p_{i,jump} = p_{jump,\min} + \frac{\rho_i - \rho_{\min}}{\rho_{\max} - \rho_{\min}} \left(p_{jump,\max} - p_{jump,\min} \right) \tag{4}$$

where ρ_i is the population density of city i, $\rho_{\min}$ and $\rho_{\max}$ represent the minimum and maximum population density of all cities, and $p_{jump,\min}$ and $p_{jump,\max}$ are two empirical lower and upper boundary values of ρ_i.

(2) *Waiting*. When the infected individual h enters into a node j that different from its original node i, it will be assigned a waiting time Δt_w that is drawn from a heavy-tailed distribution $p(\Delta t_w) \sim \Delta t_w^{-(1+\gamma)}$, where $\gamma > 0$ and $1 \le \Delta t_w \le T_{\max}$; then the individual h will wait for Δt_w time steps in node j before going to step (3).

(3) *Returning*. After waiting for time steps in node j, the infected individual h will return back to its original node i with probability p_{back} and then go to step (1); otherwise, it will turn to step (1.3) to try to do local travel with probability $p_{j,jump}$. If the trial fails, it will turn to step (1.2) to do the global travel.

In order to reduce the usage of computer memory, the passenger traveling model described above only track the traveling process of the infected individuals (including the exposed individuals), while the traveling process of the susceptible and the recovered individuals are ignored.

4. THE LOCAL INFECTION DYNAMICS

In our model, direct contacts between individuals that can potentially lead to infection are only allowed to occur within the metapopulations. The outbreak among humans would then spread globally via the railway and civil aviation transportation networks. The local infection dynamics within each node or metapopulation can be described by a stochastic Susceptible-Exposed-Infected-Recovered (SEIR) model, which is given as follows.

$$S_{i,j} + I_{i,j} \xrightarrow{p_{i,se}} E_{i,j} + I_{i,j} \tag{5.1}$$

$$E_{i,j} \xrightarrow{p_{i,ei}} I_{i,j} \tag{5.2}$$

$$I_{i,j} \xrightarrow{p_{i,ir}} R_{i,j} \tag{5.3}$$

where $S_{i,j}$, $E_{i,j}$, $I_{i,j}$, $R_{i,j}$ represents the susceptible, exposed, infected, and recovered individuals of the metapopulation $N_{i,j}$ respectively. According to the model, at each time step, i) a susceptible individual will become an exposed (infected but does not develop infectivity yet) one with probability $p_{i,se}$ for its each contact with an infected individual in the same metapopulation $N_{i,j}$; ii) the exposed individual will become infected individual with probability $p_{i,ei}$; iii) the infected individual will be recovered with probability $p_{i,ir}$.

The local infection dynamics described by Eqs. (5.1)-(5.3) are so-called individual-based simulation model. However, as mentioned in section 3.2, our model does not track the susceptible individuals, so that the Eq. (5.1) cannot be implemented at individual level. To solve this problem, we approximate the Eq. (5.1) by a stochastic equation reads

$$\frac{dS_{i,j}}{dt} = -k_i p_{i,se} \frac{I_{i,j}}{N_{i,j}} S_{i,j} + \sqrt{k_i p_{i,se} \frac{I_{i,j}}{N_{i,j}} S_{i,j}}\, \xi(t) \tag{6}$$

where $\xi(t)$ is an independent Gaussian white noise function (Watts et al., 2005), and k_i is the number of neighbors each node can contact at every time step and is given by Eq. (7):

$$k_i = k_{\min} + \frac{\rho_i - \rho_{\min}}{\rho_{\max} - \rho_{\min}} \left(k_{\max} - k_{\min}\right) \tag{7}$$

where $k_{\min}$ and $k_{\max}$ are the lower and upper boundary values of k_i respectively. This hybrid model consisting of Eqs. (5.2)-(5.3) and Eq. (6) allow us to achieve a balance between the efficiency and accuracy.

The actual process of SARS transmission will be intervened by the public health agencies inevitably and many prevention and control measures will be implemented. We have built up a simple model as given in Eq. (8) to describe the overall impact of these factors on the SARS transmission. Here, we assumed that the transmission process will be going on without any exogenous interventions and the transmission probability $p_{i,se}$ will take a constant value when $t \le t_{free}$, while the transmission probability $p_{i,se}$ will decreased exponentially if $t > t_{free}$.

$$p_{i,se}(t) = \begin{cases} 0.25, & t \le t_{free} \\ 0.002 + 0.25\exp\left(-0.13\left(t - t_{free}\right)\right), & t > t_{free} \end{cases} \tag{8}$$

5. RESULTS AND DISCUSSIONS

The model implementation is shown in Fig. 2, in which the height of the red bar represents the epidemic size of the prefecture-level city. It can be seen that the model is very suitable for simulating the geographical spread of infectious diseases. Moreover, by adjusting the model parameters, the model can apply for many different infectious diseases, such as SARS and H1N1 influenza et al., as long as the disease is transmitted through direct physical contacts between individuals. In the following discussion, we will use the model to simulate the 2003 SARS spread in China, and some preliminary results will be given and compared with the history data.

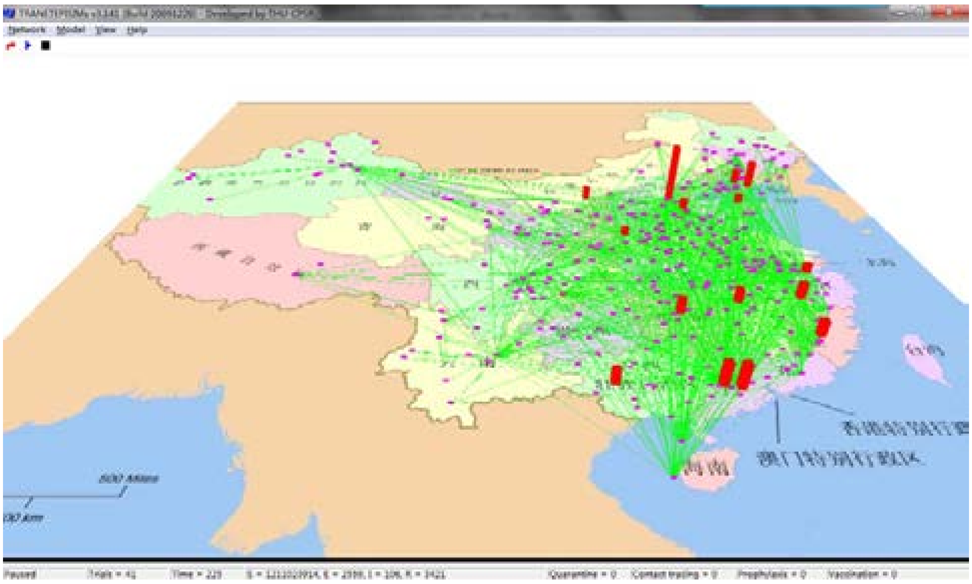

Figure 2: Model implementation.

SARS is a kind of respiratory illness that firstly occurred in Guangdong province of China in November 2002 and spread to rapidly infect individuals in some 37 countries around the world within a matter of weeks in early 2003 (Smith, 2006). There has been one near pandemic to date, between the months of November 2002 and July 2003, with 8096 known infected cases and 774 confirmed human deaths worldwide according to the World Health Organization's (WHO) 21 April 2004 concluding report (WHO, 2008). China is one of the most serious infected regions. Fig. 3(a) shows the time series of the daily new cases of SARS in China, from which we can see that there are two waves of outbreaks—the first wave is caused by the outbreaks mainly in Guangdong province and after a period of regression the disease spread to new susceptible individuals in Beijing area to make the second wave occur. The Chinese government introduced a series of powerful control measures on April 18, 2003, after which the SARS epidemic was fully contained quickly.

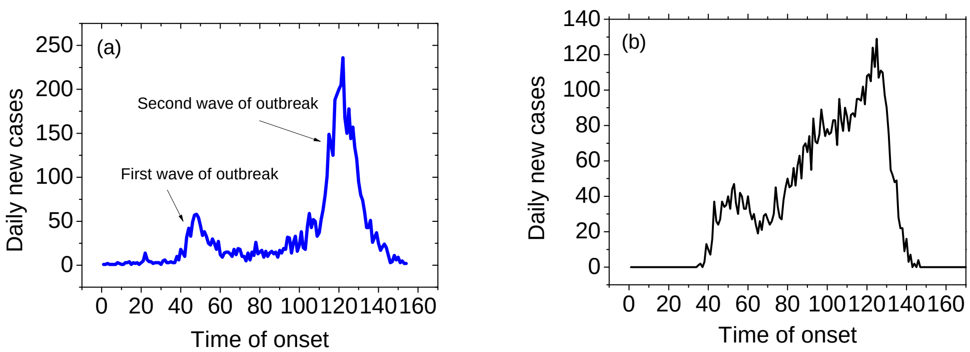

Figure 3: Time series of the daily new cases. (a) Actual data; (b) Simulated data.

The simulation was started with a single initial infection that randomly selected from Guangdong province and the result has been averaged over 5000 independent simulations. The configuration of model parameters are as follows: $\eta = 3.0$, $N_{\min} = 5\times10^3$, $N_{\max} = 5\times10^5$, $m = 3$, $\alpha = 1.0$, $\beta = 2.6$, $\gamma = 0.6$, $T_{\max} = 365$, $p_{i,ei} = 0.2$, $p_{i,ir} = 0.3$, $p_{jump,\min} = 10^{-6}$, $p_{jump,\max} = 10^{-5}$, $p_{back} = 0.85$, $k_{\min} = 4$, $k_{\max} = 12$, $d_{eff} = 5\times10^{-2}$, and $t_{free} = 120$. In Fig. 3(b), we plot the simulated curve of the daily new cases versus the time of onset. It can be noted that the simulated curve exhibits two peaks around time 50 and 120 respectively, and after about time 120, the SARS epidemic died quickly due to powerful intervention measures were initially involved in the model, which accords well with the actual data. One obvious deficiency is that the platform period after the first peak is not well reproduced by our model.

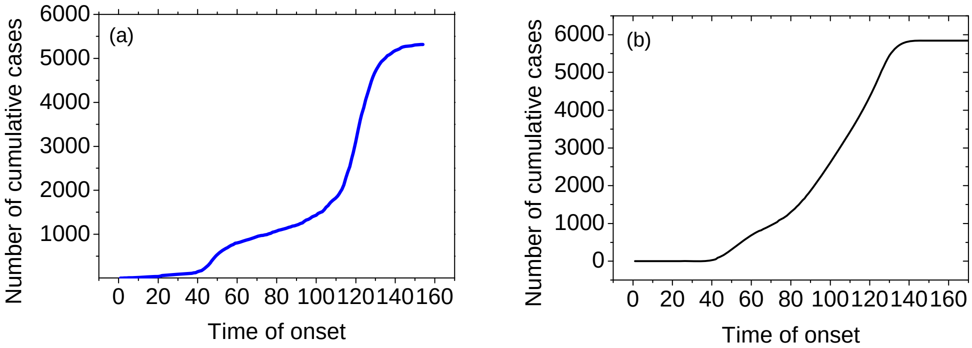

Figure 4: Time series of the cumulative cases. (a) Actual data; (b) Simulated data.

The final epidemic size of the whole country is about 5318 cases, which can be seen from Fig. 4(a)—the evolution of the number of cumulative cases as time. The corresponding simulation curve is provided in Fig. 4(b), in which the total infected cases are about 5800, slightly larger than the actual value.

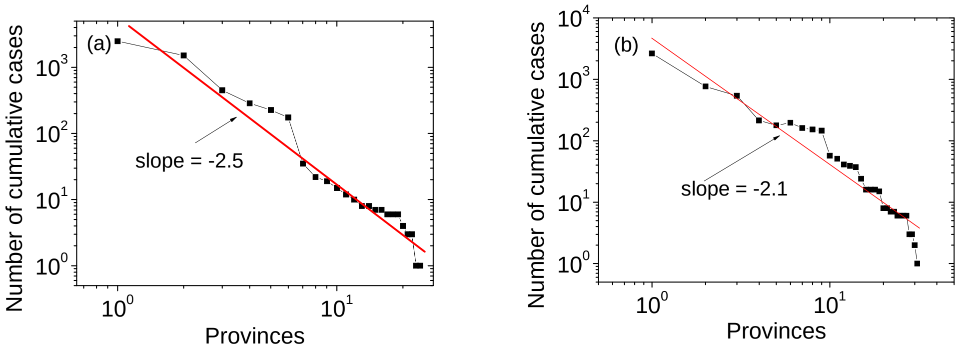

Figure 5: Final epidemic size in different provinces/autonomous regions/municipalities in China. (a) Actual data; (b) Simulated data.

Fig. 5(a) shows the geographical distribution of the number of cumulative SARS cases for different provinces (autonomous regions, municipalities) in China. Each data point in the figure is for a specific province. The slope of the solid line obtained by linear fitting is -2.5, indicating a power law behavior. In Fig. 5(b), the corresponding curve is given and the slope of the linear fitting line is -2.1, slightly less than the actual data.

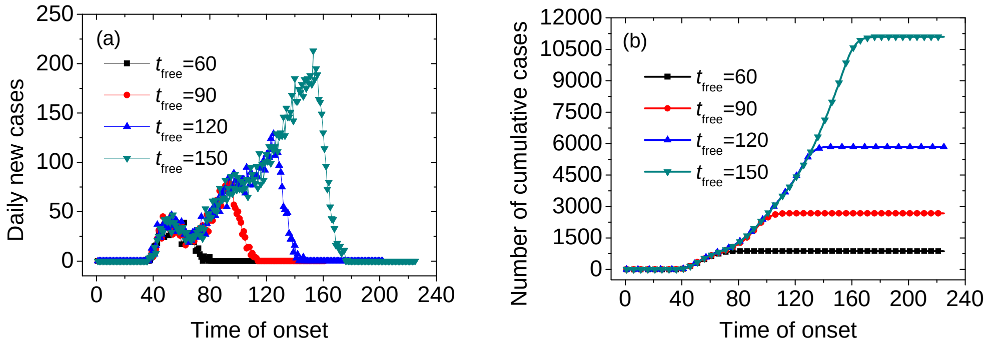

Figure 6: Influence of different intervention time on the SARS spreading. (a) Daily new cases; (b) Cumulative cases.

Finally, we studied the effects of different intervention time of prevention and control measures on the SARS spreading. Fig. 6(a) and Fig. 6(b) show the time series of daily new cases and cumulative cases respectively for different intervention time. It can be seen that the earlier the control measures take place, the better the effect of mitigating the SARS transmission. However, in reality, the prevention and control measures can inflict significant negative impact on social and economic systems if they have been taken too early, especially for a novel infectious disease. Therefore, the more reasonable strategy is to monitor the epidemic for a period of time and collect enough infected cases in the early stage to predict the trend of its propagation before taking appropriate control measures.

6. CONCLUSIONS

The objective of this research is to set up a practical framework to explore the spatiotemporal dynamics of large-scale spread of infectious diseases based on realistic mobility networks, such as railway, civil aviation and other transport networks. The population is divided into a number of metapopulations and form a three-level nested structure, i.e., the population structure of each prefecture-level city is modeled by a spatial metapopulation network and the cities are connected with each other by the railway and civil aviation networks. The dynamic passenger flow is simulated by a passenger traveling model in which the travel process, waiting process, and returning process have been described in detail.

We then introduced a hybrid stochastic Susceptible-Exposed-Infected-Recovered (SEIR) model into the framework to study the case of SARS spreading in 2003 in China. Preliminary results, including the time series of the daily new cases, the time series of cumulative cases, and the geographical distribution of the final epidemic size for different provinces indicate that our model can well reproduce the main characteristics of the SARS transmission. We also explored the impact of different intervention time of prevention and control measures on the SARS transmission and suggested that it is very important to implement appropriate control measures at right time.

It should be noted that the current model is still imperfect in following aspects. Firstly, the individuals' local travel process is subjectively approximated by the movement of individuals in the simulated spatial metapopulation networks due to the lack of statistical data of human travel within the city. Secondly, the railway network and the civil aviation network are built up on the static statistical data of the trains and the flights respectively and assume that each train or flight takes the same amount of passengers, while the real scheduling data of the trains and flights as well as the daily passengers are both dynamically changed over time. Last but not least, the effects of many measures for mitigating the SARS transmission, such as case isolation, household quarantine, exit and entry screening, contact tracing and travel restrictions, are all reflected by the same parameter of transmission probability $p_{i,se}$, which may be inconsistent with the actual situation. The future directions of improvements should be focused on the above aspects.

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REFERENCES

Hethcote, H. W., 2000. The mathematics of infectious diseases. *Siam Review* 42(4): 599-653.

Meyers, L. A., B. Pourbohloul, et al., 2005. Network theory and SARS: predicting outbreak diversity. *Journal of Theoretical Biology* 232(1): 71-81.

Yang, H. J., F. C. Zhao, et al., 2004. Modeling SARS spreading on complex networks. *International Journal of Modern Physics B* 18(17-19): 2734-2739.

Watts, D. J., R. Muhamad, et al., 2005. Multiscale, resurgent epidemics in a hierarchical metapopulation model. *Proceedings of the National Academy of Sciences of the United States of America* 102(32): 11157-11162.

Brockmann, D., L. Hufnagel, et al., 2006. The scaling laws of human travel. *Nature* 439(7075): 462-465.

Gonzalez, M. C., C. A. Hidalgo, et al., 2008. Understanding individual human mobility patterns. *Nature* 453(7196): 779-782.

Colizza, V. and A. Vespignani, 2007. Invasion threshold in heterogeneous metapopulation networks. *Physical Review Letters* 99(14): 148701.

Ni, S. J. and W. G. Weng, 2009. Impact of travel patterns on epidemic dynamics in heterogeneous spatial metapopulation networks. *Physical Review E* 79(1): 016111.

Hufnagel, L., D. Brockmann, et al., 2004. Forecast and control of epidemics in a globalized world. *Proceedings of the National Academy of Sciences of the United States of America* 101(42): 15124-15129.

Bowen, J. T. and C. Laroe, 2006. Airline networks and the international diffusion of severe acute respiratory syndrome (SARS). *Geographical Journal* 172: 130-144.

Smith, R. D., 2006. Responding to global infectious disease outbreaks, Lessons from SARS on the role of risk perception, communication and management. *Journal of Social Science and Medicine*, 63, 3113-3123

WHO. Retrieved 2008-10-31. Summary of probable SARS cases with onset of illness from 1 November 2002 to 31 July 2003.

An Event-Driven Routing Algorithm Applied for Urban Safety in Wireless Heterogeneous Networks

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ABSTRACT

In recent years, on the researches in various routing protocols, applied to wireless heterogeneous networks, become more and more important. In this paper, we propose an event-driven routing protocol applied for urban safety in wireless heterogeneous networks based on a selected knowledge discovery agent with maintaining an n-bits map table. The routing protocol can be applied to digital home wireless heterogeneous networks. It is an event-oriented routing protocol which can get more flexible and achieve fault tolerant for packet routing in wireless heterogeneous networks.

Keywords: wireless heterogeneous networks; knowledge discovery agent; bit-map; digital home networks; event-oriented

1. INTRODUCTION

Due to Internet has been development rapidly, various routing protocols, in wireless heterogeneous networks (WHNs), were proposed by researchers (Yasser et al., 2008, and Senner et al., 2008). There are various routing protocols for routing packet data in Internet. The routing protocols can be categorized into two types; one is the Global Routing (GR) algorithm, and the other one is the Decentralized Routing (DR) algorithm (Kurose *et al.*, 2007).

By way of GR algorithm, the routing path of minimum cost will be calculated between source node and destination node by gathering the topology information from global network, such as the knowledge discovery (KD) agent for topology bit-map) algorithm (Lee et al., 2008). Both RIP (Routing Information Protocol) algorithm (Malkin G., 1998) and AODV (Ad hoc On-Demand Distance Vector Routing) algorithm (Perkins *et al.*, 2003) are typical DR algorithms, in which each node only knows the costs which directly connect to other neighbor nodes. And when all nodes exchange the topology information, it will calculate its shortest path from each source node to destination node.

In this paper, we propose an event-driven (also called event-oriented, in this paper) routing protocol based on KD agent with maintaining *n*-bits map routing table (*n*-bits map KD-ED routing protocol, for short), which is suitable for WHNs urban safety environment. It is an event-oriented routing protocol which can get more flexible and achieve fault tolerant for packet routing in WHNs. In addition, the proposed routing protocol is suitable to the environment of Digital Home Wireless Heterogeneous Networks (DHWHNs).

The rest of the paper is organized as below. In Sec. II, we introduce the related works. Our scheme is proposed in Sec. III. In Sec. IV, discuss and analyze for fault tolerant for packet routing and control packet overheads. Finally, our conclusions are presented in Sec. V.

2. REVIEW OF KDATB ROUTING PROTOCOL IN (LEE *ET AL*., 2008)

In 2008, Lee *et al*. proposed a KDATB routing protocol, in which selected agent node will gather all network topology information, and then distribute a constructing bit-map routing table (BRT) to all other nodes. In BRT, a connecting state between two neighboring nodes is expressed as a binary bit. Through with the BRT, each node can decrease the overheads for maintaining its routing table (Lee *et al*., 2008). For example, a network topology is shown as Figure 1, we suppose the node 1 is an agent node which directly connects node 2 and node 3. The other nodes are nodes 4, 5, 6, 7 and 8. In Figure 1, all nodes will send a periodic 'Hello message' (Chakeres *et al*., 2002 and Lee *et al*., 2008) in order to confirm the existence of neighboring nodes. After receiving a 'Hello message' from neighboring nodes, the node will add into its neighbor information table (Lee *et al*., 2008) which consist the gathered information from all neighboring nodes. To construct the network topology, the agent node will broadcast a topology query message to all neighboring nodes. By this way, it creates a self-centered topology tree (Lee *et al*., 2008). The node, which has received the topology query message, will assign the node which has sent the message to it as the parent-node, and all other neighboring nodes are assigned to be its child-nodes. After receiving a topology query message (Lee *et al*., 2008), the node will gather all information from sub-tree or said child-nodes and send a topology reply message (Lee *et al*., 2008) to its parent-node. The topology query message consists of the node's ID, battery life-time and connectivity information (Lee *et al*., 2008). When receiving topology reply messages from other nodes, the KD agent node will collect the topology information for all nodes.

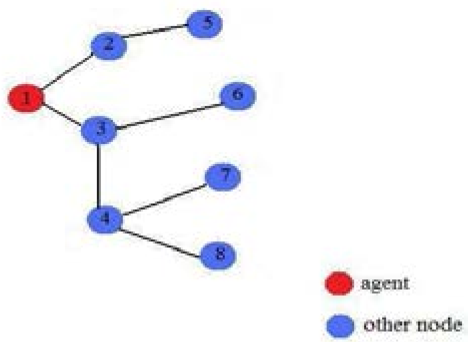


Figure 1: A network topology

After collecting all topology information, the KD agent node will create a BRT, for example, Table 1 shows a bit-map that expresses the network topology shown on Figure 1, where "1" is expressed as "one-hop distance connection" and "0" is expressed as "non one-hop distance connection".

Table 1: The corresponding BRT for network topology shown on Figure 1

Node ID \ Node ID	1	2	3	4	5	6	7	8
1	0	1	1	0	1	0	0	0
2	1	0	0	0	1	0	0	0
3	1	0	0	1	0	1	0	0
4	0	0	1	0	0	0	1	1
5	0	1	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0
7	0	0	0	1	0	0	0	0
8	0	0	0	1	0	0	0	0

Finally, the KD agent node uses the topology advertisement message (Lee *et al*., 2008) in which the bit-map table is carried and sent to other nodes. When a node needs to deliver a packet to other node, it will check the routing path by using the bit-map table. It can quickly establish multiple routing paths which include the shortest path from source node to destination node. The bit-map table represents a graph which is shown as the connected link state for all nodes in the network.

3. OUR SCHEME

In this paper, we first propose an *n*-bits map KD-ED routing protocol for WHNs urban safety environment. There are m exiting nodes in WHNs. A node c or r is one of m nodes and $c \neq r$. Within the *n*-bits map routing table (*n*-bits MRT, for short), a connecting state s_i corresponding to an event e_i between two neighboring nodes c and r, which is expressed as a binary bit $s_i \in \{0,1\}$, where "1" is expressed as "one-hop distance connection for the event e_i" and "0" is expressed as "non one-hop distance connection for the event e_i". In order to create the event-oriented routing protocol with *n*-bits MRT, we suppose there are *n* pre-defined events, which are expressed as an event set $E_{c,r} = \{e_1, e_2, ..., e_i, ... e_{n-1}, e_n\}$, where e_i is an event and *i* is the index number of the *i*-th event, $i \in \{0,1,2,..., n-1\}$ and $e_i \in E_{c,r}$. Thus, the *n* pre-defined events $E_{c,r}$ are corresponding to *n* binary bits $S_{c,r} = \{s_1, s_2, ..., s_i, ... s_{n-1}, s_n\}$ in *n*-bits MRT. When an event e_i is happened, if a node is as the intermediate node for routing the event packets, its corresponding bit will be set as $s_i = 1$ for node c and r, *i.e.* $S_{c,r} = \{s_1, s_2, ..., s_i = 1, ... s_{n-1}, s_n\}$, in its *n*-bits MRT. Otherwise, its corresponding bit will be set as $s_i = 0$ for node c and r, *i.e.* $S_{c,r} = \{s_1, s_2, ..., s_i = 0, ... s_{n-1}, s_n\}$, in its *n*-bits MRT. For example, we suppose $E_{c,r}$ is an event set, $E_{c,r} = \{e_1, e_2, e_3, e_4, e_5, e_6, e_7, e_8\} = S_{c,r} = \{01011001\}$, which there eight digital bits are corresponding to eight pre-defined events. When a node states two connections for two events e_i and e_j individually, the *n*-bits

MRT will be marked both two routes via setting the directly connection states between itself and the next-hop neighboring node for the two events, individually.

In our protocol, one border router acts as an elected KD agent for the *i-th* event, which is used to gather information and deliver the knowledge data formed into a network topology as the form of an *n*-bits MRT to all nodes. The main role of the KD agent is to gather, calculate and distribute *n*-events network topology knowledge. All nodes periodically broadcast a 'Hello message' in order to discover neighboring nodes for each event. The format of this 'Hello message' is shown in Figure 2.

Node's IP Address
The *i*-th event identity
Node's Sequence Number
Life time

Figure 2: 'Hello message' format

After receiving a 'Hello message' from neighboring nodes for the event e_1, a node generates the neighbor information and gathers them into *n-events neighbor information table*. For example, an *n-events neighbor information table* is shown in Figure 3, which shows the table collecting by an intermediate node n_1 based on Figure 6. In Figure 6, node b_1 is the KD agent and node n_1 has the following steps for gathering neighbor information:

(1) Receive topology query from nodes b_1 and n_4.

(2) Assigns node b_1 as the parent-node, and nodes l_2 and n_4 as child-nodes.

(3) Broadcasts a topology query message to child-nodes l_2 and n_4.

Node ID	Neighboring nodes	Number of neighboring nodes	The *i-th* event identity	Agent (Yes/No)
n_1	b_1, l_2 (0), n_4 (0)	3	e_1	No

Figure 3: The *i-th* event neighbor information table for node n_1

Then, the KD agent node b_1 broadcasts a query message to all neighboring nodes to collect information for constructing network topology of the *i-th* event, *i.e.* e_1. The node transmitting the topology query message becomes the parent-node, and the receivers become the child-nodes for constructing network topology of the *i-th* event. Figure 4 shows the format of the query message. By this means it constructs the *i-th* event self-centered topology tree. The node which has received the topology query message assigns the node which has sent the message to be the parent-node, and all other neighboring nodes are assigned to be child-nodes.

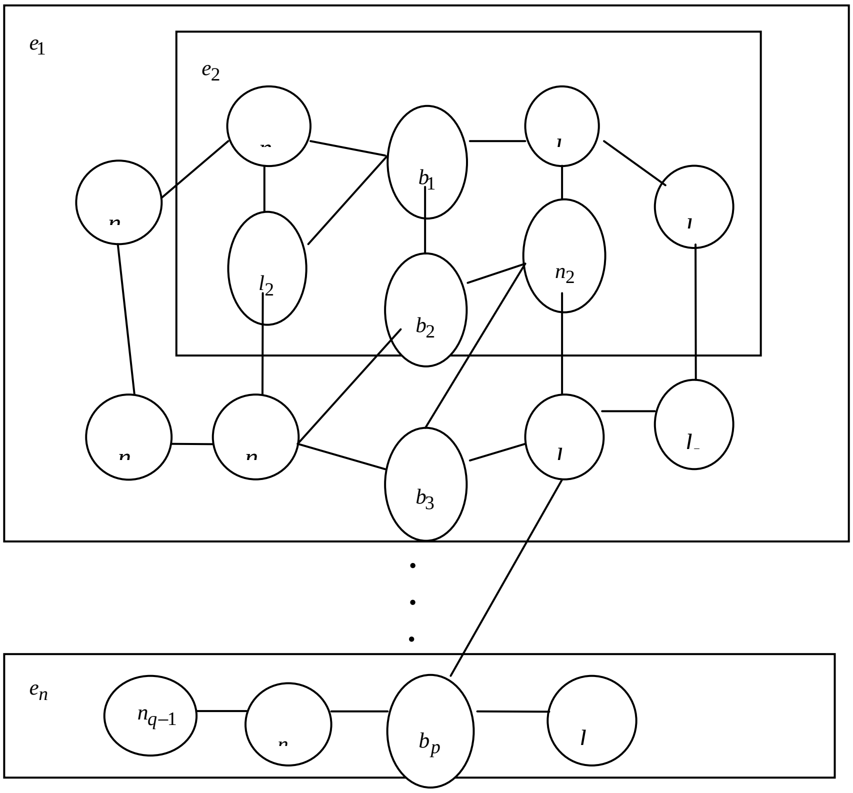
<table>
<tr><td>Type</td><td>Query ID</td><td>Event identity (the i-th event)</td><td>Reserved</td></tr>
<tr><td colspan="4">The elected KD Agent's IP address for the i-th event</td></tr>
<tr><td colspan="4">The elected KD Agent's sequence Number for the i-th event</td></tr>
</table>

Figure 4: The *i-th* event topology query message format

After receiving all topology reply messages from its child-nodes, a parent node records all information in the topology information table and transmits the information to its parent-node for the *i-th* event. Figure 5 shows the format of the *i-th* event topology reply message.

<table>
<tr><td>Type</td><td>Reply ID</td><td>Event identity (the i-th event)</td><td>Reserved</td></tr>
<tr><td colspan="4">Node IP address for the i-th event</td></tr>
<tr><td colspan="4">Neighboring node's IP address for the i-th event</td></tr>
<tr><td colspan="4">The elected KD Agent’s IP address for the i-th event</td></tr>
<tr><td colspan="4">The elected KD Agent’s sequence number for the i-th event</td></tr>
</table>

Figure 5: The *i-th* event topology query message format



$b_1 \sim b_p$: Border routers (Knowledge discovery agents)

$n_1 \sim n_q$: The 1st network nodes

$l_1 \sim l_p$: The 2nd network nodes

$e_1 \sim e_n$: Event identities

Figure 6: A topology of heterogeneous network

After receiving topology information, the agent node constructs the *n*-bits MRT, shown in Table 2, for *n*-bits map KD-ED routing protocol. Based on the *n*-bits MRT, the elected KD agent can be changed according to the following rules:

(1) The intermediate node is the preferred agent node.

(2) The agent node should have the longest battery life-time.

(3) The agent node should have as many neighboring nodes as possible.

Table 2: The *n*-bits MRT for n-bits map KD-ED routing protocol

Node ID (c) \ Node ID (r)	n_1	l_1	n_2	l_2	$\cdots$	n_{q-1}	l_{p-1}	n_q	l_p
n_1	$s_1s_2..s_n$	$s_1s_2..s_n$	$s_1s_2..s_n$	.	.	.	.	$s_1s_2..s_n$	$s_1s_2..s_n$
l_1	$s_1s_2..s_n$	$s_1s_2..s_n$	.	.	.	.	.	.	$s_1s_2..s_n$
n_2	$s_1s_2..s_n$	.	.	.	.	.	.	.	.
l_2	$s_1s_2..s_n$	.	.	.	.	.	.	.	.
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
n_{q-1}	.	.	.	.	.	.	.	.	.
l_{p-1}	.	.	.	.	.	.	.	.	.
n_q	$s_1s_2..s_n$	.	.	.	.	.	.	.	$s_1s_2..s_n$
l_p	$s_1s_2..s_n$	$s_1s_2..s_n$	.	.	.	.	.	$s_1s_2..s_n$	$s_1s_2..s_n$

Note: $E_{c,r} = \{e_1, e_2, ..., e_n\} = \{s_1 s_2 ... s_n\}$.

The elected KD agent will send the *n*-bits MRT information to all nodes in the heterogeneous network via using a topology advertisement message. Figure 7 shows the topology advertisement message format for each *i-th* event. After each node has received the topology advertisement messages, it will check whether there are any differences between this and previous topology information in order to update the *n*-bits MRT.

Type	Reply ID	Event identity (the *i-th* event)	Reserved
The elected KD Agent ID			
1-st candidate-agent node ID			
2-th candidate-agent node ID			
⋮			
(p-1)-*th* candidate-agent node ID			
The *n*-bits MRT			

Figure 7: Advertisement message format

When a node needs to transmit data to another node, it checks a routing path to the destination node by using the *n*-bits MRT. It can quickly establish the connection. The *n*-bits MRT represents a graph which shows the network topology. The pseudo algorithm for the path search process is illustrated below.

The path search algorithm for the i-th event-driven routing protocol:

Step 1**:** Perform "AND" operation with source node and destination node for the *i*-th event.

1a. if there is a path for the *i*-th event to the destination node, then go to step 3

1b. if there is no path for the *i*-th event, then go to *Step 2*.

Step 2**:** Find neighboring node for the *i*-th event.

2a. Select an unchecked neighboring node for the *i*-th event, perform "AND" operation with destination.

(1) find a path for the *i*-th event to destination, and then go to *Step 3*.

(2) if there is no path for the *i*-th event, go to *Step 2a*.

2b. when all neighbors assigning for the *i*-th event are checked, then select a neighbor and perform *Step 2*, recursively.

Step 3**:** Use searched nodes assigning for the *i*-th event for the path, and finish.

□

DISCUSSIONS AND ANALYZE

In this subsection, our proposed protocol is compared with both of traditional AODV and R-AODV (Reverse RAODV), see (Kim *et al*., 2006), in the number of control packets, shown in Table 3. We define the relevant parameters as below:

(1) *t*: number of nodes in WHNs relied on route reply message

(2) *p*+*q*: number of nodes in WHNs

(3) *n*: number of events in WHNs

Table 3: The numbers of control packet

routing protocol	***# of control packets***
AODV	(p+q)-1+t
R-AODV	2(p+q)-*2*
Our protocol	((p+q)/n)-1+t

We compare the number of control packets among AODV, R-AODV with our protocol as shown in Table 3. AODV needs to transmit the (p+q)-1+t control packets. And R-AODV needs to transmit the 2(p+q)-*2* control packets. Because of dividing the WHNs into *n* event groups, our protocol only need ((p+q)/n)-1+t control packets. Therefore, our propose protocol can reduce the number of control packets. In other words, the proposed protocol can save the power of nodes in WHNs.

If one path has interrupted, the intermediate node can easy choose a new path by using *the path search algorithm for the i-th event-oriented routing protocol algorithm* via the *n*-bits MRT. Therefore, our propose protocol can achieve fault tolerant mechanism.

CONCLUSIONS

In this paper, we first propose an n-bits map KD-ED routing protocol for WHNs urban safety environment. It is an event-oriented routing protocol which can reduce the number of control packets and achieve fault tolerant for packet routing in WHNs.

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REFERENCES

Kim C., Talipov E. and Ahn B., 2006, *A reverse AODV routing protocol in ad hoc mobile networks*, in Proceedings of Embedded and Ubiquitous Computing, vol. 4097, 522-531.

Perkins C. and Belding-Royer E., 2003, *Ad hoc On-Demand Distance Vector (AODV) Routing*, RFC 3561.

Malkin G., 1998, *RIP Version 2, RFC 2453*.

Yasser G. and Hadeel E. K., 2008, *A WSN/MANET hybrid protocol for routing data in heterogeneous wireless sensor networks*, in Proceedings of Wireless Communications and Mobile Computing, 523 - 528.

Chakeres I. D. and Belding-Royer E. M., 2002, *The utility of hello messages for determining link connectivity*, International Symposium on Wireless Personal Multimedia Communications, vol. 2, 504-508.

Kurose J. K. and Rose K. W., 2007, *Computer Networking: A Top-Down Approach*, 4th ed., New York: PEARSON.

Lee S. S., Kim H. K. and Kim C. G., 2008, *A knowledge discovery agent for a topology bit-map in ad hoc mobile networks*, Journal of Universal Computer Science, vol. 14, no. 7, 1105-1117.

Senner T., Karnapke R., Lagemann A. and Nolte J., 2008, *A combined routing layer for wireless sensor networks and mobile ad-hoc networks*, in Proceedings of Sensor Technologies and Applications, 147-153.

The Performances Study of IEEE 802.11e EDCF with TXOP in Disaster Prevention Networks

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ABSTRACT

IEEE 802.11e Enhanced Distributed Coordination Function (EDCF) is a new wireless technology in disaster prevention networks. It defines a new supplement to the existing IEEE 802.11 MAC protocol. In IEEE 802.11e EDCF, the aim is providing a QoS support in WLANs. While the system services different Access categories (ACs), IEEE 802.11e EDCF does not perform well under high load conditions. In order to improve the efficiency, we pay attention to the EDCF of IEEE 802.11e with TXOP mechanism. We first proposed a new markov chain model and studied the behavior. We extend the model to support IEEE 802.11e EDCF in wireless disaster prevention networks, and presented a more accurate analysis of the IEEE 802.11e EDCF under a non-ideal channel environment.

Keywords: WLANs, QoS, EDCF, TXOP, Block ACK

1. INTRODUCTION

In recent years, the wireless local area networks (WLANs) market is experiencing an explosive growth. The medium access control (MAC) protocol is the key element that provides the efficiency in accessing the channel, while satisfying the quality of service (QoS) requirements. IEEE 802.11e EDCF is a new wireless technology which is an enhanced version of IEEE 802.11 distributed coordination function (DCF). The IEEE 802.11e EDCF aims at improving the capabilities and efficiency of the IEEE 802.11 MAC protocol by defining a new mechanism to support the QoS services. While the system services different ACs, EDCF does not perform well under high load conditions. In order to improve the efficiency, EDCF provides two mechanisms named as transmission opportunity (TXOP) and Block ACK. These two mechanisms are allowed to offer new data transmission services that include the multiple frame delivery. There have been many performance analyses of the IEEE 802.11e EDCF. Deng and Chang proposed a priority scheme by differentiating the backoff window. Aad and Castelluccia proposed a priority scheme by differentiating inter-frame spaces (IFS's), in which a higher priority class uses IFS, whereas a lower priority class uses a space that equals the sum of IFS and the maximum window size. Veres and Campbell et al. proposed priority schemes by differentiating the minimum backoff window size and the maximum window size. These performance studies neglected that high load situation. They can not truly reflect the real operation of EDCF with priority schemes. In order to improve the efficiency, IEEE 802.11e EDCF provides two mechanisms named as TXOP and Block ACK mechanisms. In this paper, we pay attention to the EDCF of IEEE 802.11e with TXOP mechanism. We proposed a new markov chain model and studied the behavior. We extend the model to support IEEE 802.11e EDCF in wireless disaster prevention networks, and present a more accurate analysis of the IEEE 802.11e EDCF under a non-ideal channel environment.

The rest of this paper is organized as follows. In section II, a general description of our proposed model with TXOP mechanism **is** presented. Analytical performance deviations of proposed model with RTS/CTS and basic access mechanisms including throughput analysis under a non-ideal channel scenario are presented in section III. The numerical results are given with discussion in section IV. Finally, conclusions are drawn in section V.

2. OVERVIEW OF IEEE 802.11E EDCF MODEL

2.1 The System Model

IEEE 802.11e is a feasible scheme for different QoS requirements. In IEEE 802.11e, the contention-based access mechanism is called an enhanced DCF (EDCF). EDCF specifies four default access categories, which are shown in Table 1.

Table 1: Priority to AC mappings

	(UP – Same as 802.1D User Priority)	Designation	Category (AC)	(Informative)
lowest	1	BK	AC_BK	Background
	2	-	AC_BK	Background
	0	BE	AC_BE	Best Effort
↓	3	EE	AC_BE	Video
	4	CL	AC_VI	Video
	5	VI	AC_VI	Video
	6	VO	AC_VO	Voice
highest	7	NC	AC_VO	Voice

Each STA contends for the channel access and independently starts its backoff depending on its associated AC. Each AC uses AIFS[AC], CW_{min}[AC] and

CW_{max}[AC] instead of DIFS, CW_{min} and CW_{max} of the DCF. The contention method of EDCF is the same as that in DCF. Each STA having a frame to transmit has to wait for the channel to be idle without interruption for a period AIFS[AC], and then it should start a random backoff process with its own *CW*[AC]. For each time slot interval, during which the channel stays idle, the random backoff value is decremented. When the backoff counter reaches zero, the frame is transmitted. AIFS[AC] is calculated as follows:

$$\text{AIFS[AC]} = \text{AIFSN[AC]} * \text{aSlotTime} + \text{aSIFSTime}, \quad (1)$$

where AIFSN[AC] is shown in Table 2 and the backoff time is calculated as follows:

$$\text{backoff time} = \text{random\_integer} * \text{aSlotTime}, \quad (2)$$

where random_integer is uniformly and randomly chosen in the range [0,*CW*(AC)], instead of [0,W-1] in the DCF. *CW* of each AC is equal to CW_{min}[AC]. After each collision, *CW* is doubled up to:

$$CW_{\max}[\text{AC}] = 2^{\text{m}} * (CW_{\min}[\text{AC}]), \quad (3)$$

where m is called the maximum backoff stage. Once it reaches CW_{max}[AC].

Table 2: AIFSN for each ACs

AC	AC_BK	AC_BE	AC_VI	AC_VO
AIFSN	7	3	2	2

The timing diagram of the EDCF is shown in Figure 1

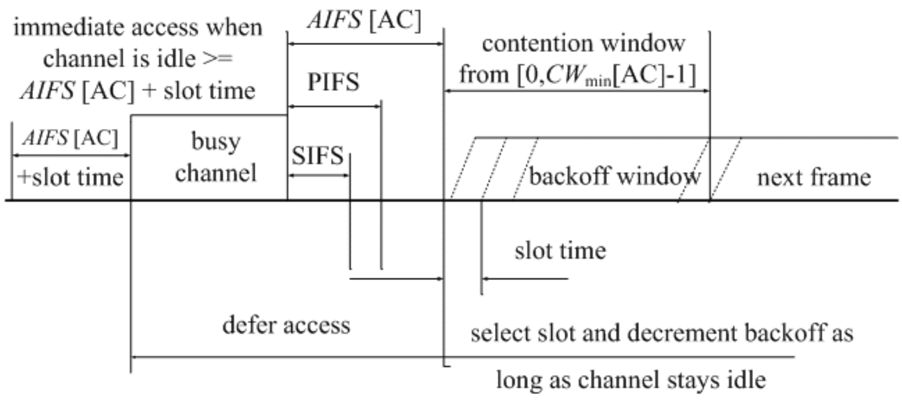

Figure 1: The timing diagram of the EDCF

We assume in the following that for a given station in the priority *i* class, $b(i,t)$ is defined as a random process representing the value of backoff counter at time *t*, and $s(i,t)$ is defined as the random process representing the backoff stage j , where $0 \leq j \leq m$ and *m* is the maximum backoff stage. The value of the backoff counter is uniformly chosen in the range $(0,1,......W_{i,j} - 1)$, where $W_{i,j} = 2^j W_{i,0}$ and $W_{i,0} = CW_{\min}[i]$. Let p_i denote the probability that a transmitted frame collides in the priority i class. A Markov chain $\{s(i,t), b(i,t)\}$ can be established to analyze the contention process. Therefore, the state of each station in the priority i class is described by $\{i, j, k\}$, where i is just an index standing for the priority i class, j stands for the backoff stage and takes values $(0,1,...,m)$, and k stands for the backoff delay and takes values $(0,1,......,W_{i,j}-1)$ in time slots. The proposed Markov chain model is shown in Figure 2

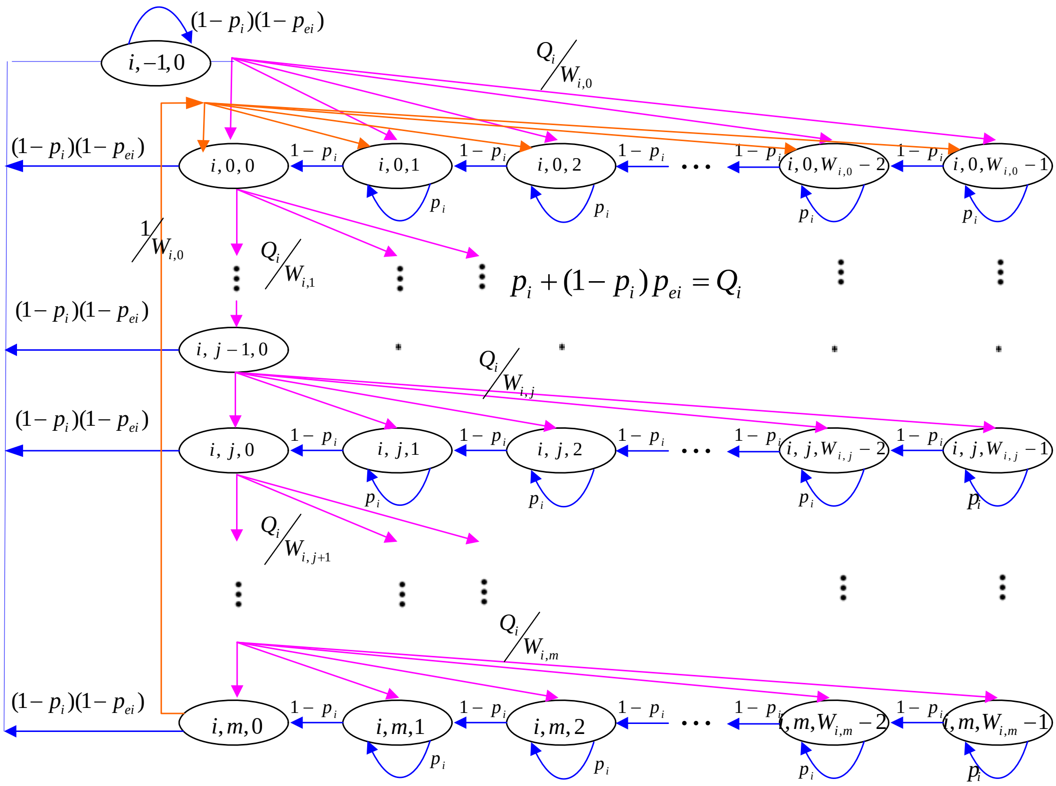

Figure 2 : Markov chain model for the priority i with the backoff window size under channel error scenario

The contention window size at the backoff stage j in the priority i class is defined as $W_{i,j}$. For convenience, $W_{i,j}=2^j W_{i,0}$, where $j \in [0,m]$ is called the backoff stage, $W_{i,0}$ is the initial contention window size in the priority i class, and m is the maximum backoff stage. For each STA, the backoff window size at the backoff stage j in the priority i class can be shown as

$$W_{i,j}=\begin{cases} 2^j W_{i,0}, & j \le m \\ 2^m W_{i,0}, & j>m \end{cases} \quad (4)$$

Where $2^m W_{i,0}-1=CW_{\max}$. Let p_i denote the probability that a transmitted frame collides in the priority i class:

$$p_i = 1-\left(\prod_{h=0}^{i-1}(1-\tau_h)^{n_h}\right)(1-\tau_i)^{n_i-1}\left(\prod_{h=i+1}^{N-1}(1-\tau_h)^{n_h}\right). \quad (5)$$

Let $p_{s,i}$ denote the probability that a successful transmission occurs in a time slot for the priority *i* class. We then have

$$p_{s,i} = n_i \tau_i (1-\tau_i)^{n_i - 1} \prod_{h=0, h\neq i}^{N-1} (1-\tau_h)^{n_h}. \quad (6)$$

From the state transition diagram for the priority *i* class as shown in Fig. 2. The transmission probabilities of the Markov chain model are listed as follows:

1. The backoff counter decrements when the STA senses that the channel is idle at the beginning of each slot time in the priority *i* class:

$$P\{i, j, k | i, j, k+1\} = 1 - p_i, \ 0 \le k \le W_{i,j} - 2, \ 0 \le j \le m. \quad (7)$$

2. The backoff counter freezes when the STA senses that the channel is busy in the priority *i* class:

. $$P\{i, j, k | i, j, k\} = p_i, \ 0 \le k \le W_{i,j} - 1, \ 0 \le j \le m. \quad (8)$$

3. The STA enters the {*i*, -1, 0}state if it verifies a successful transmission without any channel errors:

$$P\{i, -1, 0 | i, j, 0\} = (1 - p_i)(1 - p_{e,i}), \ 0 \le j \le m. \quad (9)$$

   Where $P_{e,i}$ is the packet error rate for the priority *i* class.

4. The STA transmits it frame without entering the backoff process if it detects that its previous transmitted frame was successfully received, the channel is idle, and has no channel errors:

$$P\{i, -1, 0 | i, -1, 0\} = (1 - p_i)(1 - p_{e,i}), \ 0 \le j \le m. \quad (10)$$

5. If the STA finds a collision has occurred or has any channel errors, the STA defers to transmit a new frame and enters stage 0 to start the backoff process:

$$P\{i, 0, k | i, -1, 0\} = \frac{p_i + (1 - p_i) p_{e,i}}{W_{i,0}}, \ 0 \le k \le W_{i,0} - 1. \quad (11)$$

6. The STA chooses a backoff time slot of the next stage *j* after an unsuccessful transmission at stage *j*-1 in the priority *i* class:

$$P\{i, j, k | i, j-1, 0\} = \frac{p_i + (1 - p_i) p_{e,i}}{W_{i,j}}, \ 1 \le j \le m, \ 0 \le k \le W_{i,j} - 1, \quad (12)$$

7. At the maximum backoff stage, the contention window will be reset to the initial value due to discarding the frame caused by too many retransmissions:

$$P\{i, 0, k | i, m, 0\} = \frac{1}{W_{i,0}}. \quad (13)$$

2.2 TXOP Mechanism

In IEEE 802.11e, the TXOP is a time period when a particular station (STA) that wins the channel access has the right to initiate transmission along with the EDCF parameters of AIFS[AC], CW_{min}[AC], and CW_{max}[AC]. During the TXOP, STA is allowed to transmit more than one frame with a short inter-frame (SIFS) time gap between an ACK and the subsequent frame transmission without the backoff process Since SIFS is used for frame separations, the other STAs cannot gain channel access because they must wait at least a DIFS interval. The TXOP frame structure is shown in Fig. 3.

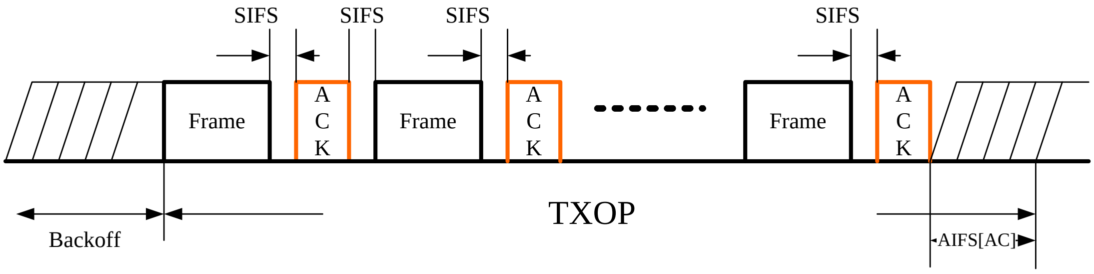

Figure 3 : TXOP frame structure

3. PERFORMANCE ANALYSIS OF EDCF WITH TXOP MECHANISM

3.1 Saturation Throughput and Delay Analysis of EDCF with TXOP Mechanism

From the analysis that was depicted in the previous section II, the transmission probability is related to *CW* size and AIFS[AC]. When deriving the saturation throughput with different TXOP durations, the collision probability and the transmission probability of a STA are the same as those derived in section II. However, the equations relating to the transmission time of each successful contention will be different for the different ACs, i.e., different ACs are assigned different TXOP durations. We assume that the system is under an environment of channel error and having the RTS/CTS CSMA/CA mechanism. Thus, we can obtain

$$S_i = \frac{p_{s,i} * E[T_{L_i}]}{(1-p_i)\sigma + \sum_{i=0}^{N-1} p_{s,i}\left(1-P_{e,i}\right)T_{S,i} + [p_i - p_{s,i}]T_{C,i} + \sum_{i=0}^{N-1} p_{s,i}\left(P_{e,i}^{RTS}T_{e,i}^{RTS} + P_{e,i}^{CTS}T_{e,i}^{CTS} + P_{e,i}^{DATA}T_{e,i}^{DATA} + P_{e,i}^{ACK}T_{e,i}^{ACK}\right)} \tag{14}$$

$$E[T_{L_i}] = \{\sum_{l=1}^{K_i-1} l*((1-P_{e,i})(1-\hat{P}_{e,i})^{l-1}\hat{P}_{e,i}) + K_i*(1-P_{e,i})(1-\hat{P}_{e,i})^{K_i-1}\}*T_{L_i}. \tag{15}$$

$$T_{S,i} = T_{RTS} + T_{CTS} + 2T_{SIFS} + k_i*(T_{Li} + T_{ACK} + 2T_{SIFS}) + AIFS(i), \tag{16}$$

where $T_{S,i}$ is the TXOP duration which equals the time needed to successively transmit k_i frames. When the system is under the environment of a channel error, there are three kinds of transmission error frames: 1) The RTS/CTS frames transmission error. When the RTS/CTS frames transmit an error, the STA cannot determine whether the error is caused by a collision or channel error. 2) The data frames transmission error. 3) The ACK frames transmission error. The probabilities of an unsuccessful transmission can be written as:

$$P_{e,i} = 1-\left(1-P_b\right)^{L_{RTS}+L_{CTS}+L_i+L_{ACK}}. \tag{17}$$

$$\hat{P}_{e,i} = 1-\left(1-P_b\right)^{L_i}. \tag{18}$$

$$P_{e,i}^{RTS} = 1-\left(1-P_b\right)^{L_{RTS}}. \tag{19}$$

$$P_{e,i}^{CTS} = \left(1-P_b\right)^{L_{RTS}}\left(1-\left(1-P_b\right)^{L_{CTS}}\right). \tag{20}$$

$$P_{e,i}^{DATA} = \left(1-P_b\right)^{L_{RTS}+L_{CTS}}\left(1-\left(1-P_b\right)^{L_i}\right). \tag{21}$$

$$P_{e,i}^{ACK} = \left(1-P_b\right)^{L_{RTS}+L_{CTS}+L_i}\left(1-\left(1-P_b\right)^{L_{ACK}}\right). \qquad (22)$$

Where P_b is the bit error rate, and L_{xxx} is the length of different types of frames. $P_{e,i}^{xxx}$ is the frame error rate of the frame type xxx for the priority *i* class.

4. NUMERICAL RESULTS

In this section we assume that the DBPSK (Differential Binary Phase Shift Keying) modulation scheme is used in the simulation. Then, we can calculate the required SNR at the receiver by using the following equation:

$$SNR = 2*(erfc^{-1}(2P_b))^2. \qquad (23)$$

$$P_b = \frac{1}{2} erfc(\sqrt{\frac{SNR}{2}}). \qquad (24)$$

We finished the analysis the TXOP mechanism with the RTS/CTS CSMA/CA access scheme under the channel error scenarios and compared it with the model that is without the TXOP mechanism. Fig. 4 shows the saturation throughput performance of the TXOP mechanism with the RTS/CTS CSMA/CA access scheme for different priority STAs under channel error scenario. Figure 5 depicts the saturation throughput performance of different priority STAs using the RTS/CTS CSMA/CA access scheme without the TXOP mechanism under channel error scenario. From the results, we can conclude that the model with the TXOP mechanism under channel error scenario can achieve higher performance than the model that is without the TXOP mechanism because the model with the TXOP mechanism is allowed to transmit more than one frame with a short inter-frame (SIFS) time gap between an ACK and the subsequent frame transmission without the backoff process.

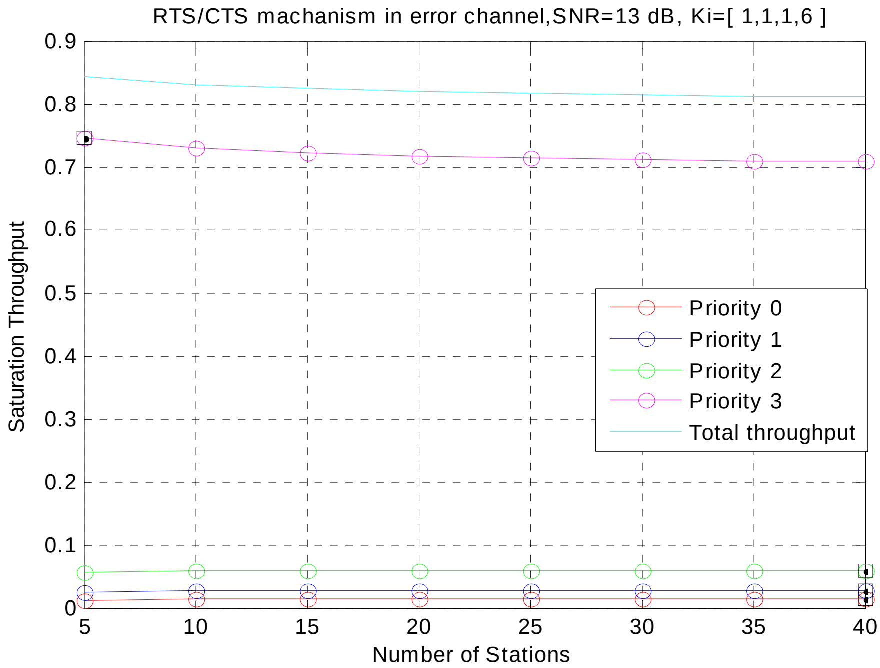

Figure 4 : Saturation throughput of the different priority STAs with the TXOP mechanism under a channel error scenario, Ki=[1,1,1,6].

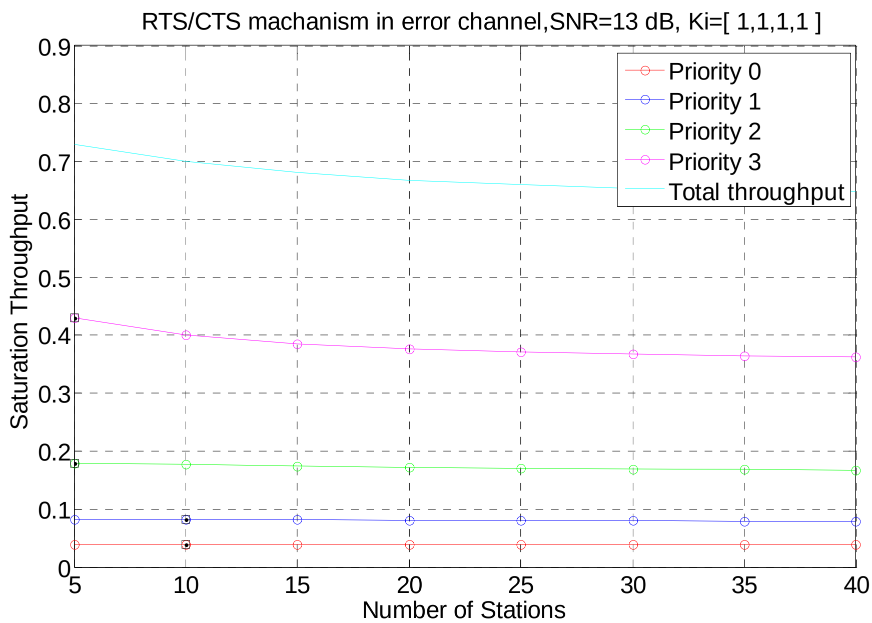

Figure 5 : Saturation throughput of the different priority STAs with the TXOP mechanism under a channel error scenario, Ki=[1,1,1,1].

5. Conclusions

In this paper, an improved analytical model was proposed to study the behaviors of the backoff process in terms of saturation throughput. In order to be suitable for the QoS requirements, we extended the model to support the multi-priority schemes under non-ideal channel scenarios. In order to improve the efficiency, we integrate the TXOP mechanism in a non-ideal channel scenario.The model with the TXOP mechanism under a channel error scenario can achieve a higher performance than that without the TXOP mechanism due to fact that the proposed model with the TXOP mechanism is allowed to transmit multiple frames during the TXOP duration.

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REFERENCES

D. J. Deng and R. S. Chang, "*A priority Scheme for IEEE 802.11 DCF Access Method*," IEICE Trans. Communications., Vol. E82-B, No.1, Jan. 1999, pp.96-102.

I. Aad and C. Castelluccia, "*Differentiation Mechanisms for IEEE 802.11*," IEEE INFOCOM 2001.

A. Veres, A. T. Campbell, M. Barry, and L.-H. Sun, "*Supporting Differentiation in Wireless Packet Networks Using Distributed Control*," IEEE J-SAC, Vol. 19. No. 10, Oct. 2001, pp. 2081-2093.

Y Xiao, "*QoS guarantee and provisioning at the contention-based wireless MAC layer in the IEEE 802.11e wireless LANs,*" IEEE Wireless Communications Magazine, vol. 13, pp. 14-21, Feb. 2006.

Daqing Gu and Jinyun Zhang, "*QoS enhancement in IEEE 802.11 wireless local area networks*," IEEE Communications Magazine, vol. 41, pp. 120-124, June 2003

S. Choi, J. del Prado, S. Shankar N, and S. Mangold, "*IEEE 802.11e contention-based channel access (EDCF) performance evaluation*," Proceedings of the IEEE International Conference on Communications, May 2003.

The Development of Disaster Prevention and Response Information Platform in Yunlin, Taiwan

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ABSTRACT

Due to the occurrence of natural disasters is on an upward trend in Taiwan, Yunlin County Government promotes 5-year Disaster Prevention and Response Operation Plan that follows the experience of previous similar activities. The government chooses the high risk disaster hotspots – Gukeng Township, Taixi Township, Dapi Township, Kouhu Township, and Douliu City as the targets of this plan. Hereby, we select Gukeng and Taixi Townships which are areas of higher risk disaster as examples to explain the details.

There are many problems with disaster recovery in those five townships before the deployment of this plan. For example, the lack of equipments and the difficulty in collecting real time information have delayed the rescue of disasters. To improve the abilities of disaster recovery for these local governments, the main purpose of this project is to help them enhance Disaster Emergency Operation Center (DEO Center) and implement Disaster Prevention and Response Information Platform （DPRIP）. The existing DEO Centers in above-mentioned local governments lack for information and communication equipment, and the staffs have difficulties in receiving the disaster messages to handle the disaster in time. In addition, lots of paper works in the disaster prevention and relief workflow have made the processes inefficient. To solve the problems, this project intends to provide suitable space and needed hardware and software equipment to enhanced DEO Centers. DPRIP is a web-based platform to replace the existing paper-based workflow for staff to receive information in time. With enhanced DEO Centers and DPRIP, the local governments can handle the disaster relief work more efficiently and increase the capacity and quality of disaster prevention and relief.

Keywords: *disaster emergency operation center, web-based platform*

1. INTRODUCTION

With global climate change, the frequency of disaster in Taiwan is increasing. The 921 earthquake in 1999 and the 88 flood in 2009 had brought a great loss to the society. To prevent the similar disaster, Taiwan's regional governments have been planning for disaster prevention policy, so that they can take the relief action immediately when the disaster occurs. Besides, most of the cities in Taiwan are either near coastline or mountains. Taixi Township (台西鄉) is a typical coastal township and Gukeng Township (古坑鄉) is a hill township, and both of them are the most serious disaster townships in Yunlin county (雲林縣) Therefore, we choose Taixi and Gukeng as according examples to demonstrate how to enhance their Disaster Emergency Operation Centers (DEO Center) and implement Disaster Prevention and Response Information Platform (DPRIP) for them.

1.1 The Terrain And The Conceivable Disasters Of Taixi Township

Taixi is located at the western coastal areas of Yunlin, and it faces the Taiwan Strait (Figure 1). The most area of Taixi is dominated by flat plains that cover about 75% of the whole land with the land elevation of about five meters. There are three drainages – Cailiao (才寮), Huoshaoniuchou (火燒牛稠), and Chenghaicuo (程海厝), which intersect with Taixi from east to west and flow into Taiwan Strait. In regard to the climate, the mostly rainy season is during summer, southwest monsoon is during spring, and northeast monsoon is during fall and winter; high temperature is in summer and fall, and cold temperature is in winter and spring. The conceivable disasters of Taixi are classified into several different categories, such as typhoon, earthquake, and others. From July to September in summer, the typhoon forms on Western Pacific, and brings abundant rainfall to the local area. Additionally, Taixi has serious problem with land subsidence. Once typhoon or torrential rain comes, it will cause flood and make great loss to agricultural and fishing industries. The earthquake did not cause too much damage in Taixi. But to prevent the loss from the possible earthquake, we still made the earthquake as a part of the disaster prevention plan. In addition, because of being close to No.6 Naphtha Cracker Industrial park, it might cause some kinds of disasters like chemistry, fire, and traffic disaster.

1.2 The Terrain And The Conceivable Disasters Of Gukeng Township

In contrast to Taixi, Gukeng is located at the eastern mountain area of Yunlin (Figure 1). The region of Gukeng is dominated by hills and mountains, and the land elevation is between 60 to 1750 meters. The possible disasters here are classified into several different categories: typhoon, slope, earthquake, and others. In regard to typhoon, even though Gukeng do not have the problem with land subsidence, but flood is still formed at rural village where near the drainages when typhoon or torrential rain comes. And because Gukeng is slopeland area, it even might occurs debris flow and landslide. For example, KALMAEGI (卡玫基颱風)

and SINLAKU (辛樂克颱風) in 2008 cause many debris flows in Gukeng and the landslide in Caoling (草嶺). The earthquake is also an important part of disaster prevention plan in Gukeng. The 921 earthquake in 1999 had caused the collapse of building and Caoling landslide on Jhuo-Shuei River (清水溪) that led to“quake lake”. Yunlin County Government has been promoting the tourism industry in Gukeng, so the famous Janfusun Fancyworld, Janfusun Prince Hotel, and HuaShan (華山) Coffee attract many tourists on holidays. We consider that the traffic accidents may be included in the disaster prevention plan because of the heavy traffic.

Figure 1: Maps of Yunlin County and Taixi and Gukeng Townships

2. PROBLEMS TO BE SETTLED

The problems of the existing Disaster Emergency Operation Center (DEO Center) are that they need more professionals of disaster prevention and response than they have. Due to the shortage of the finance and human resource, the staffs seldom have enough drill for disaster prevention and relief. So they lack of autonomy and capabilities for disaster prevention and relief. The workflow of the disaster prevention and response is also inefficient because a lot of paperwork needed to be filled up. Therefore, we plan to design the Disaster Prevention and Response Information Platform (DPRIP) to relieve the staffs from the inefficient paperwork to enhance their capacity and quality of disaster prevention and response.

2.1 The Present Situation Of Disaster Management In Gukeng Township

The chief and deputy commander of the DEO center are taken by the mayor and chief secretary respectively. The task forces consist of relevant officials and administrators according to the necessity of the disaster prevention and response. The debris flow occurs frequently in this township, and some areas are easy to have the mountain torrents and flood disaster situation. Therefore, the township aggressively pushes the disaster prevention works. They usually hold a Disaster Prevention and Response Council. When the disaster occurs, the DEO center will be set up in the briefing room on the second floor of the town hall. However, the local government still suffers from lacking good capacity and quality of disaster prevention staffs, and lots of paper works in the disaster prevention and relief workflow have made the processes inefficient. Due to the shortage of sufficient funds and human resources, the local government doesn’t have related experience and self-governing ability. There is still room for improvement about disaster prevention.

2.2 The Present Situation Of Disaster Management In Taixi Township

As Gukeng Township, the town mayor and chief secretary of Taixi Township are the chief and assistant commander of DEO center. The task forces also consist of relevant officials and administrators according to the necessity of the disaster prevention and response. When the disaster occurs, the DEO center will be set up to resolve everything about disaster relief. However, because of insufficient space in the Taixi town hall, the local government doesn’t allocate an exclusive space for DEO center. However, the staffs appointed for the disaster prevention are rotated very often, so the experience and knowledge of disaster prevention cannot pass down. This makes them not able to react to the urgent event correctly and might make a wrong decision. They usually have to wait for the instructions from the superiors when the disaster occurs. This local government needs more assistance from county government and the relevant experts to enhance their disaster prevention skills.

3. IMPLEMENTATION

In order to enhance the capabilities of disaster recovery for these five townships in Yunlin, such as Gukeng Township, Taixi Township, Dapi Township, Kouhu Township, and Douliu City, we interviewed the relevant officials of the five townships to understand the current processes and guidelines of operating in the field and make appropriate recommendations accordingly. During the interview with the officials, we want to know that what kind of features the local governments want for the DPRIP, how many software and hardware equipments they already have, and whether the five townships have established the DEO Center or not. If they haven't established the DEO Center, we will counsel with them about their requirements and expectations for the DEO center.

3.1 The Deployment For DPRIP

The purpose of DPRIP is for local officials to exchange related documents, share results of the latest disaster information, integrate geographic information, and offer expert experience and potential analysis. The home page of DPRIP is shown in Figure 2. In this section, the functions and content of DPRIP were introduced as the following: the front-end processing functions, the back-end processing functions and the system use case diagram.

Figure 2: The home page of DPRIP

3.1.1 Front-End Processing Functions

The front-end functions of DPRIP are cataloged into two major parts: information search and data register. The features of the functions are discussed as following:

(1) DPRIP follows the framework of Web 2.0 to provide information service to residents and relevant officials. DPRIP is a web application which can be accessed through the internet. It provides dynamic HTML web pages created from continuously updated database. Therefore, DPRIP can provide residents and relevant officials continuously updated information as long as their linking to DPRIP website.

(2) DPRIP intends to offer citizens complete disaster prevention and response information. Ordinary people can browse the following web pages such as: organization introduction, disaster prevention, publicity, disaster list, history

records, related websites, and so forth (Figure 3). The contents of these pages are listed as following:

a. Organization Introduction: Organization Chart, Disaster Prevention and Response Act, Disaster Prevention and Response Plan, and Standard Operating Procedure (SOP).
b. Disaster Prevention Information: News, Weather Report, Rainfall Forecasting, Earthquakes, Evacuation Shelters, Debris Flow Alert Areas.
c. Publicity: Report and Multimedia Demonstration.
d. Disaster List: List for Flooded Area, Debris Flow Area, Landslide Area, Rural Villages In Danger.
e. History Records: Serious Disaster Cases, Reports, and Image Database.
f. Related Websites: Workshops and Related Links.
g. File Download: Related Files For Visitors To Download.
h. Volunteer: Volunteer Registration Form
i. Donation: Donation Registration Form

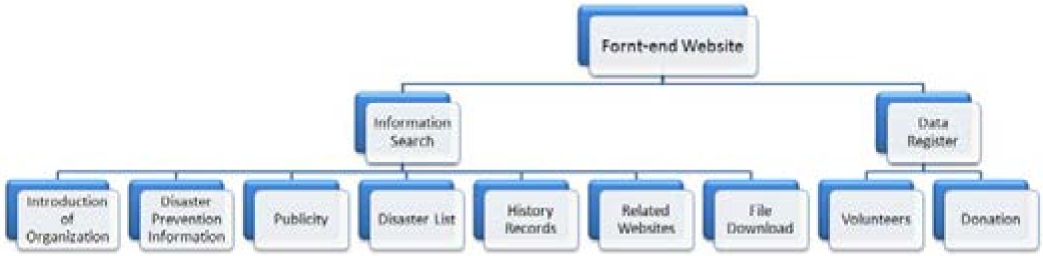

Figure 3: Front-end processing functions

3.1.2 Back-End Processing Functions

The back-end processing functions of DPRIP are for system administrators to manage the web site. The features of the functions are discussed as following:

(1) Files management system: DPRIP provides on-line files management system for administrators to upload related documents to information platform. Ordinary people can get what they need quickly according to the classification of files.

(2) Electronic administrative system: In addition to files management system, DPRIP also provides disaster notification system, human resource system, and goods and materials system for DEO Center to deal quickly with the information of rescuers, volunteers, goods and materials, and disaster notification records (Figure 4). These features are explained as following:

a. Website Management: Website management allows web administrators to insert, update, and delete web page.
b. Access Control Management: Access control management is used to grants different users, such as visitors, officials, and administrators, different levels of authority. Different users are allowed to access different information as long as permissible.
c. Donation Management: Web administrators can use this function to insert, delete, update, and query data for donated goods and materials.

The announcement of needed goods and materials is made for people to donate needs voluntarily.

d. Disaster Management: Through this function, web administrators can insert, delete, update, and query disaster information according to the current situation of disaster.

e. Human Resource Management: This function is for web administrators to insert, delete, update, query human resources information, and make announcements for human resources requirement. The administrator can also search, group, and adjust task force according to the requirement from each township.

Figure 4: Back-end processing functions

3.1.3 System Use Case Diagram

There are three kind of actors in DPRIP, such as visitor, official and administrator (Figure 5). DPRIP consists of two processors: one is front end processor and the other one is back end processor. All processing functions can be used by officials and administrators, but visitors can only use front-end processing functions. The front end processor has two major functions: information search and data register. The information search provides all actors as many functions as shown in figure 3. The functions provided by back-end processor are shown in figure 4.

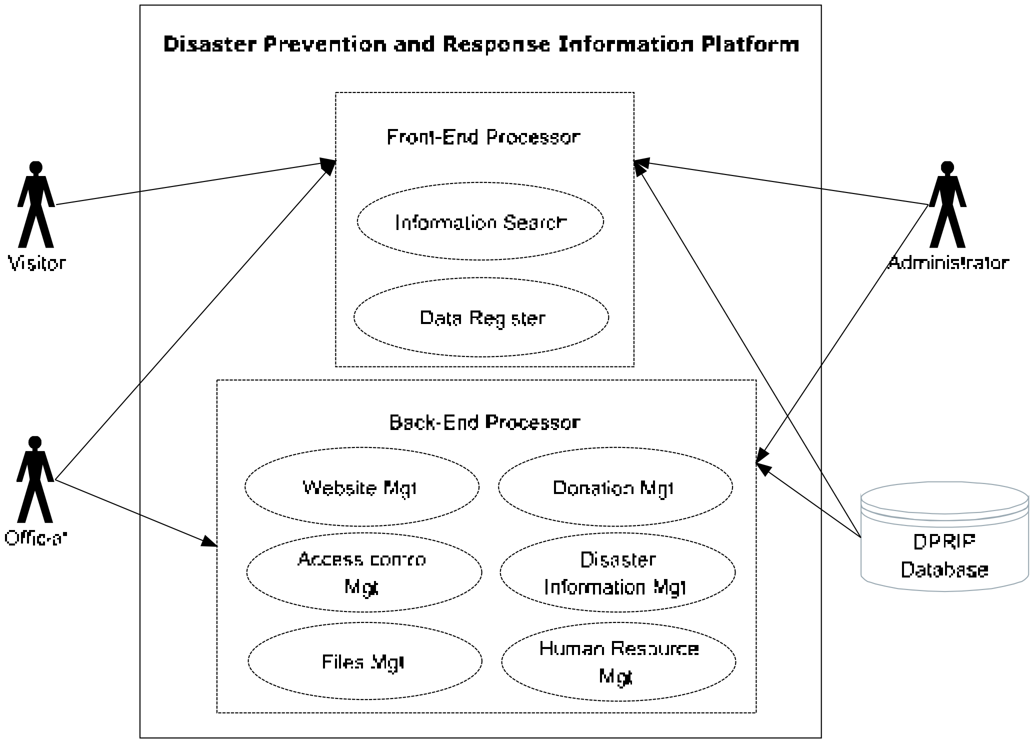

Figure 5: Use case diagram of DPRIP

3.2 The Deployments Of Hardware Equipment And DEO Center

(1) Gukeng Township

Gukeng Township has settled their DEO center in the briefing room on the second floor of the town hall. There are projector, network and broadcasting equipment in the room. In addition, we suggest them to have a liquid crystal display TV for acquiring information from television news. Regarding the mobility of notebooks, we recommend that each task unit to have their own notebook in order to collect information and make crossing comparison as needed. Moreover, the notebook has not only an advantage of working in the power failure but also a webcam to support video conference. Since there is only one network line now, we will add both the wired and wireless network to support the network connection. We also suggest that each unit at least has a telephone respectively to communicate with each other as needed for exchanging information of disaster. Furthermore, the regional government has a satellite phone, but the regional government is not afforded to use it. And only few people know how to operate it. We recommended that every village have their own radio set. Thus, the disaster information can be transferred immediately when other communication devices are down. If it is impossible to make every village have their own wireless device, we can deploy wireless devices to the villages in alert area first.

(2) Taixi Township

The DEO center of Taixi Township is not in the town hall but in a conference room on the second floor of the next building for Mediation Committee. There are not any network, projector, and broadcasting equipment in that room. Firstly, the conference room must be set up the network and the telephone line, and then a set of a liquid crystal display TV, a projector, and the network and broadcasting equipments. Besides, there is no disposition of safeguard. In consideration of security and mobility, we recommended that each unit of the task force to have their own notebook for video conferencing with the superiors, collecting information and making crossing comparison. Since, there is no network line, we will deploy wired and wireless network as soon as possible. We also suggested that each task unit has a telephone respectively. Furthermore, the regional government has a satellite phone, but it is too expensive for them to use. We recommended that every village has a radio set in case of all other communication devices are broken. If it is not afforded to make every village have radio sets, those villages in alert area must have high priority. Regarding peripheral equipment, we suggest them to use all-in-one printer for paper processing. According to the previous disaster, we find that the continual supply of electric power is the most important factor while disaster happens. So we suggest that there should be Uninterruptible Power Supply (UPS) or electronic storage devices. Additionally, there are not any security systems, so we suggested that there should be a security system to keep the equipments from being stolen in the DEO center.

4. CONCLUSION

This project is for deploying DPRIP and DEO Centers in five townships in Yunlin County, so that township officials can exchange related documents, share the latest disaster information, get message in real time and make the right decisions. As the result of rapid decision making and information acquiring, they improved the efficiency of disaster response and reduced the decision error rate and cost of decision making. In addition, there are future plans for this project which are discussed as the following.

(1) Training workshop for disaster prevention and response are going to be held to enhance the ability of collecting and reporting disaster-related information in village and township offices, so DPRIP and DEO Centers can really work out and reach their goal.

(2) Make the DPRIP to have overall resources about disaster prevention and response, historical disaster data, disaster prevention and response act, standard operating procedure, and prevention method.

In order to make this project be implemented and promoted successfully, the interaction with the township officials is very important. The discussion between project developers and township officials will be held continually to ensure that every requirement can be heard during the period of project execution. And according to the requirements, an appropriate platform will be established to make the disaster prevention and response work successfully. Moreover, it can increase the ability of disaster prevention and response and reduce the damage from disasters.

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REFERENCES

National Disaster Prevention and Protection Commission, R.O.C, 2003.5. Three-year medium-term plan of enhancement of disaster prevention and rescue ability in regions, Taiwan.

National Disaster Prevention and Protection Commission, R.O.C, 2008.1. Five-year medium-term plan of disaster prevention and rescue, Taiwan.

National Fire Agency, Ministry of the Interior, Website: http://www.nfa.gov.tw/

National Disaster Prevention and Protection Commission, R.O.C, Website: http://www.ndppc.nat.gov.tw/

National Yunlin University of Science and Technology, 2004.11. Detailed plan application of united Institute plan subsidized by National Disaster Prevention and Protection Technology Center, Taiwan.

National Yunlin University of Science and Technology, 2005.12. The 94th annual year plan of enhancement of disaster prevention and rescue ability in Yunlin County, Taiwan.

National Yunlin University of Science and Technology, 2006.12. The 95th annual year plan of enhancement of disaster prevention and rescue ability in Yunlin County, Taiwan.

National Yunlin University of Science and Technology, 2007.7. Plan of enhancement of disaster prevention and rescue ability in Yunlin County, Taiwan.

National Yunlin University of Science and Technology, 2010.4. Final report on long-term disaster prevention and rescue plan, Taiwan.

Taipei City Disaster Prevention and Rescue Information, Website: http://tdprc2.tfd.gov.tw/TaipeiCityEms1_public/

Taipei County Disaster Prevention and Rescue Information, Website: http://www.dsc.tpc.gov.tw/home.asp?Pager=Link.asp&Kind=00173

Yunlin Fire-Fighting Department, Website: http://www.ylfire.gov.tw/

MISSIONS AND PARTICULAR ACTIVITIES OF THE CENTER FOR ADVANCED ENGINEERING STRUCTURAL ASSESSMENT AND RESERACH, CAESAR

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ABSTRACT

With recent rapid increase in demand for structural condition assessment and rehabilitation of existing highway bridges the Center for Advanced Engineering Structural Assessment and Research, CAESAR, was established in April 2008, as one of four Research Institutes and Centers of the Public Works Research Institute, Tsukuba, Japan. This paper presents a review of the background, mission, organization, and research areas of CAESAR, in addition to their expected impacts on highway bridge administration practices.

1. INTRODUCTION

Public Works Research Institute, which is one of the Japanese incorporated administrative agencies, established the Center for Advanced Engineering Structural Assessment and Research (CAESAR) as of April 1st, 2008, recognizing increased social needs for appropriate maintenance of existing structures. As a core research center in Japan, it accumulates findings related to maintenance technology of the structures. This paper describes the background of establishment of CAESAR, organization and system, mission, and new activities.

2. BACKGROUND

The majority of highway bridges in Japan were constructed during the 1950s–1970s, which coincides with Japan's high-growth period. Accordingly, bridges older than 50 years will increase drastically in the coming years (Figure 1). Moreover, highway bridges in Japan are exposed to severe automobile traffic and natural environment; it is highly probable that the deterioration and damage will increase rapidly. Consequently, under tight financial circumstances, technologies related to inspection, assessment, diagnosis, repair, and reinforcement should be established urgently for the sake of preventive maintenance.

However, many instances of damage such as fatigue of floor slabs, fatigue of steel girders and beams, and salt corrosion and alkali-silica reaction of concrete members have already been recognized as the national major defects, which strongly influence bridge load-bearing characteristics (Figure 2). For example, such trouble was reported in 2006 that a fatigue crack exceeding 1 m in length developed in a main girder of a steel girder bridge around a part welded to a cross beam (Yamazoe Bridge, National Route 25). In 2007, a tension diagonal bracing of a steel truss bridge (Kiso River Greater Bridge, National Route 23, Honjyo Ohashi, National Route 7) fractured because of corrosion. In all these cases, traffic restrictions were enforced temporarily for repair, resulting in a considerable social impact. Regarding overseas trouble, the I-35W Bridge (Minneapolis, Minnesota, U.S.) collapsed in August 2007 despite the fact that detailed inspections, actual bridge measurements, and status assessments had been carried out annually.

In Japan, infrastructure was heavily damaged by the Hyogo-ken Nanbu (Kobe) Earthquake in 1995. In recent years, large-scale earthquakes have occurred successively: the Niigata Chuetsu Earthquake in 2004, the Noto Peninsula Earthquake and Niigata Chuetsu-Oki Earthquake in 2007, in addition to the Iwate-Miyagi Inland Earthquake in 2008. Improvement of disaster prevention and mitigation technologies has been requested to cope with the increasing sophistication of socioeconomic activities.

3. ORGANIZATION AND SYSTEM

CAESAR is one of four research organizations constituting the Public Works Research Institute. The research teams of bridge engineering, foundation engineering, management, and earthquake engineering were restructured, with staff at the establishment of CAESAR of 22 (as of Sept 2010). In addition, five researchers from the Tsukuba Central Research Institute and Civil Engineering Research Institute for Cold Region are also on call so that construction material and severe cold environment effect can be also covered.

CAESAR tackles every research need in a flexible fashion, covering a wider range of the bridge engineering field. It does not employ a conventional research organization system of PWRI to create organizations and systems. While the PWRI’s former highway bridge-related research teams were organized in terms of major highway bridge components and materials (such as metal superstructures, concrete superstructures, substructures, and seismic design), CAESAR adopted a radically different approach, -- one where interdisciplinary communication and support are stressed. The rehabilitation and seismic reinforcement of older bridges involve a much more multifaceted and complicated series of issues than those encountered during conventional design/construction efforts. For older bridges, a comprehensive structural assessment of the entire structure is often required. For example, when designing a seismic reinforcement of an existing steel bridge, the structure's overall state of deterioration and the possible negative side effects of the planned reinforcement method on the fatigue vulnerability must be taken into account. Therefore, in CAESAR, now researchers are assigned on a project-by-project basis to ensure interdisciplinary collaboration across all disciplines.

As shown in Figure 3, respective specialists of superstructure, substructure, earthquake engineering, fundamental materials, and cold region construction technology promote research and technical development. This group also is intended to be an organization with abundant comprehensive strength for design and construction, disaster mitigation, inspection, diagnosis and prognosis, rehabilitation and reinforcement, and management systems. Areas of the superstructure to substructure of the bridge are considered as a total system.

Research coordinator for earthquake engineering is responsible for organizing individual research projects related to earthquake engineering including bridges and other road and river structures covered by all PWRI's research institutes and centers. When a large-scale earthquake occurs, the coordinator urgently summons researchers from CAESAR, Tsukuba Central Research Institute, and Civil Engineering Research Institute for Cold Region to send an emergency survey team. When required by the regional development bureau and local public authorities after the earthquake, the coordinator also directs technical assistance activities.

4. ROLES AND ACTIVITIES

CAESAR provides technical supports to highway administrators and conducts research with a much closer relationship with them, as shown in Figure 4. CAESAR especially covers highly sophisticated issues for which relevant diagnosis and prognosis technique, assessment method, or corrective method has not been generally understood. While highway administrators need information to judge how serious that damage is, how soon it should be treated, and what remedial method should be chosen or what, CAESAR provides technical assistance using cutting-edge technology even though it is in the middle of development. For example, Figure 5 shows an example of an on-site test of the on-going project of a fatigue prevention technique for steel deck plates utilizing SFRC (steel fiber reinforced concrete) pavement. In addition, CAESAR continues follow-up activities after an assessment was conducted or a corrective measure was taken. While CAESAR accumulates findings from the site, it develops and improves cutting-edge technology to resolve such an issue. That's what CAESAR calls scientific trials. CAESAR pursues this kind of win-win cycle between highway administrators and the CAESAR's research activities.

CAESAR also intends to be the meeting ground of highway administrators, academic sector, and private sector to shear and exchange state-of-the-art information and yield collaborations.

Then CAESAR's know-how based on the findings obtained through the scientific trial and meeting ground are presented by technical guidelines and reports as well as a knowledge database for engineers that will be developed. CAESAR also continues to contribute to developing national technical standards as the Tsukuba Research Institute done before. It is crucial that experiences and findings obtained through scientific trials be fed back successively to the design and construction of new bridges and be fed back to the rehabilitation of existing bridges to make bridges easier to maintain and have a longer service life.

5. RESEARCH AND DEVELOPMENT BASED ON SCIENTIFIC TRIALS AND AN AUTOPSY APPROACH

CAESAR keeps many basic research projects going in the laboratory to understand the mechanism of deterioration and repair. However, CAESAR will keep going not only as the way we did in the laboratory but also promote a scientific trial approach in the field much more. Structural conditions, construction status (initial construction quality, etc.), and environmental and traffic conditions are different bridge by bridge. Therefore, CAESAR assigns greater importance to a scientific trial approach to resolve technical issues for maintaining individual bridges rather than laboratory study with prescribed conditions.

5.1 Inspection

The development of non-destructive test (NDT) tools is highly expected. NDT tools in the market are supposed to work based on theoretical background and laboratory tests but they sometimes do not work well in the field. Accordingly, we have started a project in cooperation of highway administrators. In 2009, we applied NDT tools such as measurement of ultrasonic propagation velocity for a 45yrs-old bridge damaged by ASR to evaluate the accuracy and feasibility of the tools in terms of physical characteristics of damaged concrete (Figure 6). Moreover we plan to give opportunities to industry to test many kinds of nondestructive testing tools. The result on accuracy and feasibility will be shared with highway administrators and developers. We expect that this effort will show developers the clear needs of improvement and highway administrators the potentials of newer technology.

5.2 Autopsy and scientific trials using decommissioned bridges

When any damage is noticed for a certain structural member or portion of the bridge, the urgency, priority, and required level of corrective action depends on how much that damage can affect the bridge system structural performance. Because each bridge has the uncertainty of structural conditions, it is difficult to assess the precise degree of structural soundness. Now CAESAR and highway administrators cooperatively conduct several projects in autopsy survey using bridges that will be decommissioned. Figure 11 illustrates a concept of the autopsy research approach for structural safety assessment.

For example, as for concrete bridges, we conduct load tests using bridges that will be decommissioned or members that were replaced while we also disassemble them to survey the corrosion of reinforcement, deterioration of concrete, and so on. Using this approach, we will associate the actual load bearing capacity of older or damaged bridges with the degree and condition of damage and develop a methodology to identify relevant numerical parameters for calculation, resulting in the assessment of the remaining load bearing capacity and deterioration rate of older or damaged bridges. This research also may lead to set replacement criteria for older bridges in the future.

The on-going project that should be highly intriguing is using a large-span steel truss and girder bridge of Choushi Oh-hashi bridge which suffered severe corrosion damage (Figure 7). After the decommission, several components of the bridge were sampled to transport to the CAESAR large-scale structural test laboratories. CAESAR researchers will scrutinize many issues to improve the inspection technique for finding structural deficiencies and the prediction technique for estimating the remaining strength of deteriorated critical structural components. For example, the strength of those members is also going to be tested and compared with numerical predictions. As of Sept 2010, the researchers already have conducted a visual-based bridge inspection, truck loading test on site, measurement of remaining steel thickness of corroded components, and vibration test. In addition, they also have looked over the history of earlier rehabilitation works and started furnishing finite element models.

5.3 Follow-up investigation of repair/rehabilitation case histories

CAESAR conducts a three-year project to design the follow-up database for the effectiveness and durability of earlier repair and rehabilitation work in actual bridges in real environments. Most corrective measures/chemicals/materials come to the market via laboratory tests and theoretical research. However, they often do not have sufficient data in the field to see if those are effective and durable in any conditions. We acknowledged that sometimes they work well and sometimes they do not work well for bridge by bridge. Accordingly, the follow-up database will give highway administrators the direction of relevant choice of repair and rehabilitation methods considering the surrounded environment, age, bridge structural type, position and type of structural members, level of deterioration and damage, traffic volume etc.

So far, as stated above, seeds of industry and needs of highway administrators are somewhat different. The follow-up database also will give strong directions to industry what is needed, what should be improved, and what should be tested before hitting the market.

5.4 Long-term bridge monitoring of deterioration

Long-term bridge monitoring is also a key to model the deterioration of bridges and verify design technology for durability. However, long-term and reliable observation results in the field are rare. It is therefore necessary to accumulate findings associating continuous monitoring data, periodical thorough inspection results, and the change in the load-bearing characteristic of the structure with each other. CAESAR and Okinawa Prefecture have started a 100-year collaborative project to obtain the long-term observation data for chloride-induced deterioration of concrete bridges. Okinawa islands are the southern part of Japan and designated in the code as the region at which a special treatment is required for preventing chloride-induced deterioration. Many bridges in the islands suffer from chloride-induced deterioration and there are many long span bridges between islands. Accordingly, the effective data acquisition is a keen strategy to conduct preventive maintenance at the right time with the right method. Irabu Oh-hashi Bridge, which is a prestressed concrete bridge, is designed under the latest codes of practice in terms of the durability against chloride-induced deterioration. It is now under construction and will be completed in 2012. In some parts, the cover concrete of the piers is designed to have an additional thickness so that samples can be obtained to monitor the time evolution in the chloride penetration into concrete during 100 years after the completion. When the sampling will be conducted, many NDT tools also will be tested for comparison. In addition, many sample specimens are also going to be made when the concrete is cast at piers and will be delivered to exposure tests. We will see the differences in the deterioration condition of the piers for a long time because of the deference in the fresh concrete quality, cement quality, and environmental conditions. On top of that, other 10 bridges with longer spans also will be inspected to model the time evolution of the on-site chloride penetration and strength of concrete. This project is very beneficial for both parties to establish reasonable behavior curves, so that they will be able to make the bridges' lives longer than 100 years.

We expect that this kind of long-term observation, follow-up investigation of earlier corrective measures, and autopsy survey of heavily damaged bridges will strongly improve the micromanagement technology of individual bridges such as behavior curves, reasonable structural safety evaluation algorithms, and the right choice and timing of method to repair.

6. EARTHQUAKE ENGINEERING

Earthquake engineering is another key technology in CAESAR, and the scientific trial approach is also adopted. For example, CAESAR supports highway administrators when they reinforced older bridges against strong

earthquakes, and the bridges that were reinforced based on a PWRI research result had no serious damage in recent strong earthquakes. Now CAESAR keeps improving post-earthquake strengthening methods for RC piers, testing very rapid repair work methods that are simple, easy, and fast, and which utilize materials that are easy to obtain, such as carbon-fiber sheet and polyester bands (Figure 8).
Moreover CAESAR dedicates to international cooperation activities for the seismic damage investigation and the technical supports of the repair and retrofit after an earthquake. On February 27, 2010, an intensive earthquake of the magnitude 8.8 occurred in Chile. With the request from Japan Society of Civil Engineering (JSCE), CAESAR dispatched Chief Researcher to Chile with the schedule from March 27 to April 7, 2010 as the reconnaissance investigation group member of JSCE. Investigation results and unseating mechanism of the damaged bridge were immediately reported to bridge administrators in Chile. The seismic design technique developed in Japan was also introduced to them with the traffic serviceability judgment based on the damage in bridge and technical information for improving the seismic performance of Chilean bridges. Those activities conducted in Chile have affected the new Chilean seismic design manual established in July 2010, in which the seismic design recommendations of the unseating prevention system in Japan were introduced.

7. STANDARDIZATION OF VERIFICATION MEASURES

CAESAR will address standardization of rehabilitation technologies. The point is that it will also include a verification measure to confirm whether a proposed repair or a rehabilitation/reinforcement technique meets the performance requirements under given various conditions and to clarify the limitation of application. For example, the PWRI's standard tests for the fatigue durability of deck plates and the seismic ductility for piers have been gaining wide acceptance.

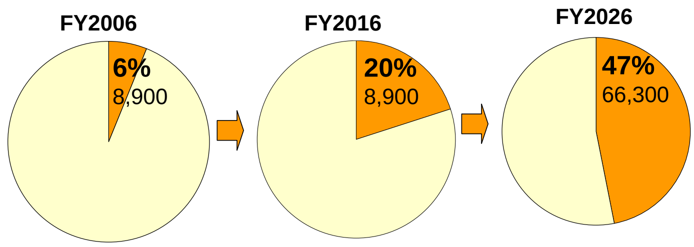
CAESAR takes over the mission to develop the Japanese Specifications for Highway Bridges and other design directions and guidance that were originally undertaken by the Tsukuba Central Research Institute, because it is very important that findings obtained through corrective actions and disaster mitigations have to be fed back sequentially to the design and construction of new bridges. For example, problems are often related to the initial construction and design qualities. CAESAR has been preparing for the next revision of the Japanese Specifications for Highway Bridges, which will be based on a performance-based specification concept, involving a reliability design concept.

8. REMARKS

CAESAR is organized especially to be able to respond precisely and timely to needs of society and highway administrators in a flexible manner beyond the framework of typical studies in the laboratory. The scientific trail approach is considered to be crucial while basic research also runs. The acronym CAESAR was inspired by Julius Caesar of the Roman Empire, who established and maintained the infrastructure of long empire-wide highway network -- parts of which are still in use more than 2000 years later. We hope our new CAESAR research center will forge ahead with an equally strong will, and thus ensure we can complete our missions. Collaborative work with related research organizations will be highly appreciated.

REFERENCES

Road Bureau, MLIT, 2007–2008. Data presented to the Expert Meeting on Preventive Maintenance of Highway Bridges, Data for press appeared on the Road Bureau website.
MLIT Technical Investigation Team for the 2007 Minneapolis bridge collapse, 2007. Technical investigation report on the 2007 Minneapolis bridge collapse.



(Total # of bridges in 2006 ~ 140,000)

Figure 1: Percentage of bridges of ages 50 and older (No shorter than 15 m)

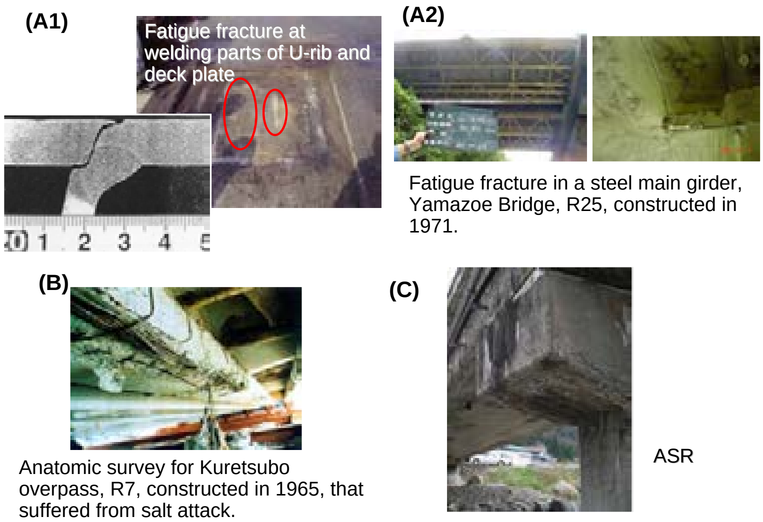


Figure 2: Three major types of distress that severely impact bridge strength capacity: A = fatigue fracture in steel members, B = chloride-induced deterioration of concrete structures, and C = alkali silica reaction of concrete structures.

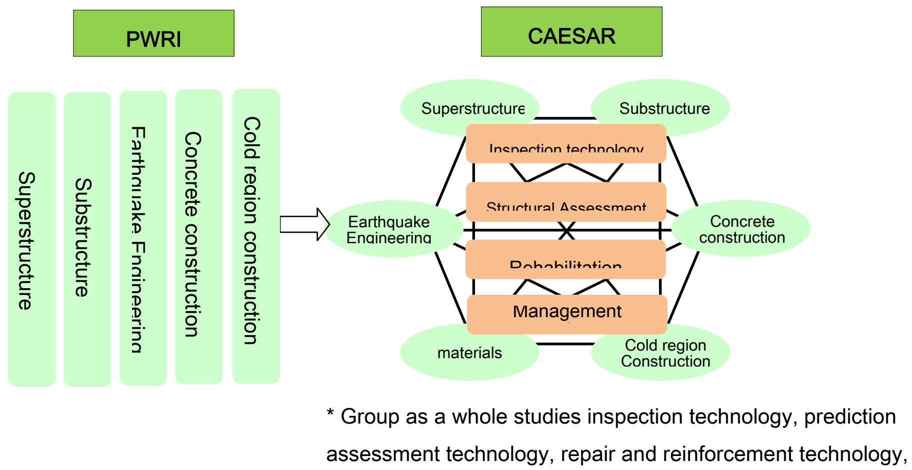


Figure 3: Difference between conventional organization and CAESAR related to bridges in the Public Works Research Institute

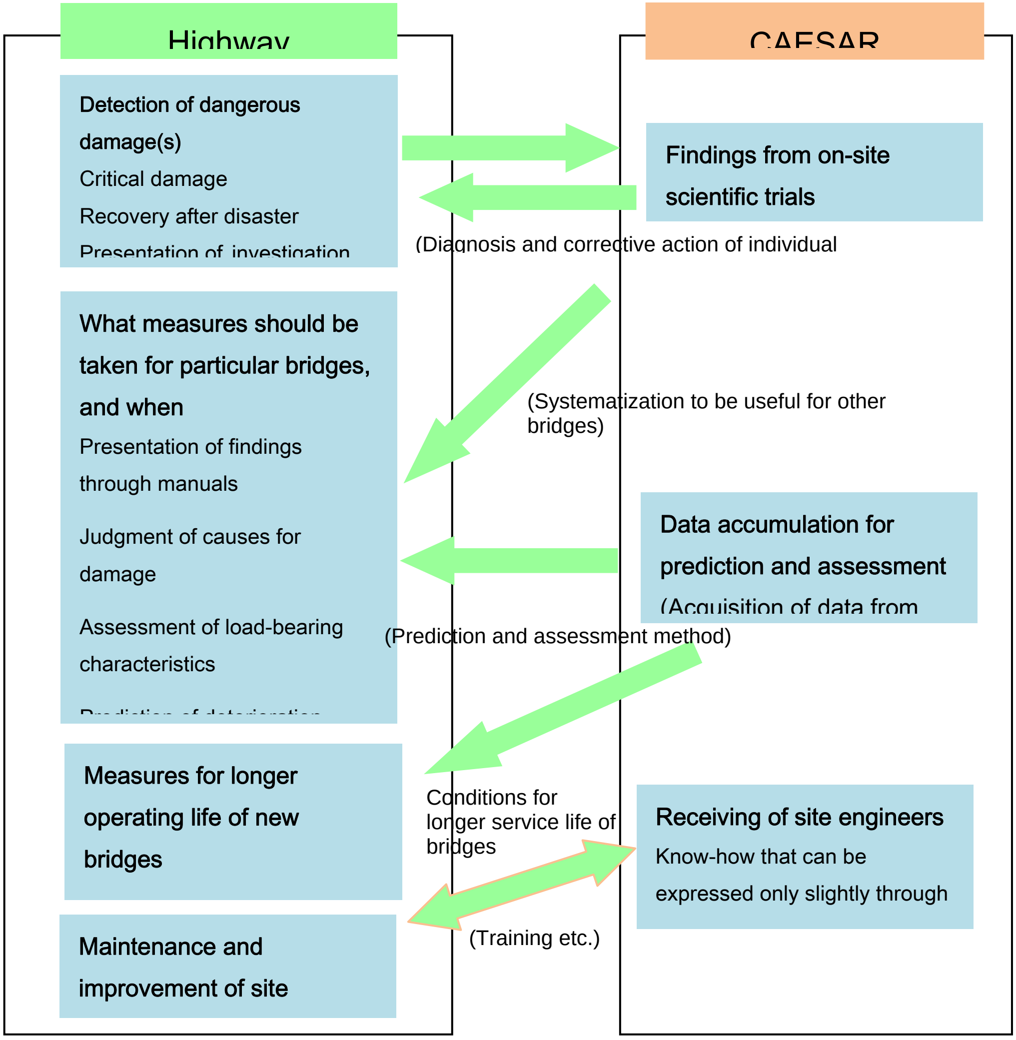


Figure 4: Scientific trials: a cycle of a technical assistance for highway administrators and the corresponding research activities of CAESAR

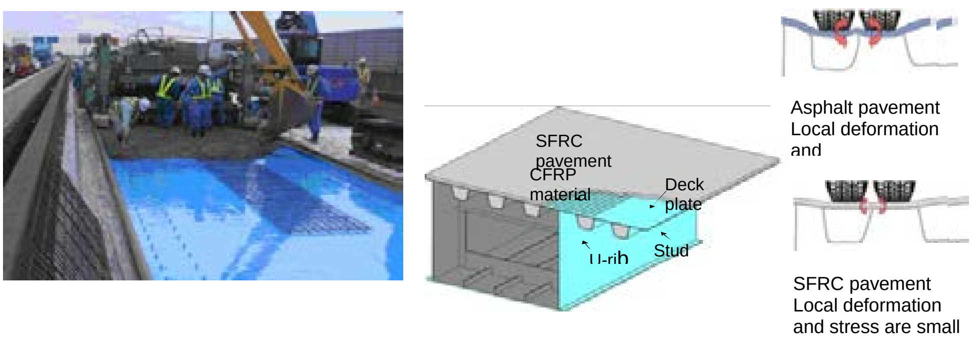


Figure 5: Fatigue durability improvement technology of existing steel floor slab using steel fiber reinforcement concrete (SFRC)

Crack at a pier by ASR

Measuring ultrasonic propagation velocity

Figure 6: Measuring ultrasonic propagation velocity for a ASR-damaged bridge

Figure 7: Choshi Oh-hashi Bridge and deterioration of the members

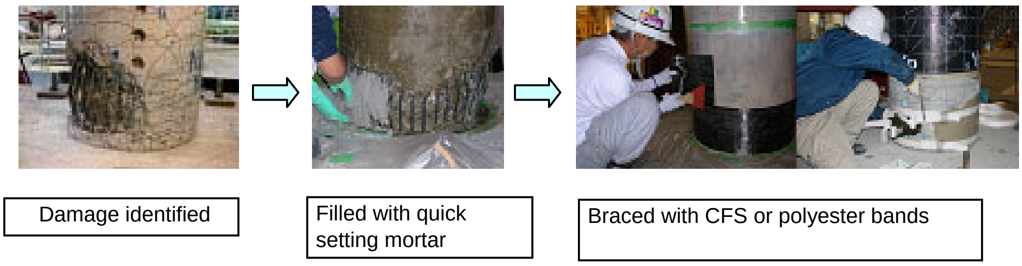


Figure 8: Easy-to-apply emergency recovery technology for RC bridge columns after an earthquake

Introduction to possible natural disaster and problems of urban development in Mongolia

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ABSTRACT

Mongolia is a country where various natural disasters occur frequently: blizzard; heavy snow "ZUD"; dust storm; rain water flood; dibaish flow; snow melt flow; earthquake; and others such as wildfire; drought; and desertification. Blizzards occur generally between September and May. Duration may be short, just a few hours, or up to 10 days, but it can be extremely dangerous with heavy snow and up to 35 m/s wind. Heavy snow fall disasters differ from blizzards in that persons are not so much at risk. Damage is primarily caused by livestock being immobilized on the range or in shelters and unable to reach grazing. Extreme snow falls are up to 1.5 m in mountain areas. Transport becomes difficult with snow falls greater than 40 cm. Earthquakes are quite frequent in some parts of Mongolia. The consequences in villages are generally destruction of housing, roads and bridges. The traditional "GER" houses are very resistant to earthquake damage. According to the statistical report, biggest earthquake was occurred in the Gobi Altai mountain on 1957 and killed 1200 person; wind storm on 2001, killed 16 person and flood occurred on 2003, killed 15 person. The Government of Mongolia is responsible for all activities related to prevention and mitigation of all types of natural disaster. In 1990, the Government of Mongolia established the State Permanent Emergency Commission (SPEC) in order to coordinate activities among the government agencies against any type of natural disaster. Mongolia still does not have reliable earthquake-resistant construction technology. In Mongolia, there are very few buildings equipped with earthquake-resistant facilities and means. However, "GER" houses are more resistant to earthquake they can be damaged, but to a lesser extent than conventional buildings. Since 1990, a decentralization policy for people and industry has been effected in urban development planning and regional development. Due to accelerated urbanization in the last three decades, the demand for house building has increased greatly. In this connection, a large number of 5-12 storey apartments have been built in the cities. The government is taking measures to improve the system for natural disaster preventing and reduce losses and damages that may affect social, economic, and ecological values, and reduce the vulnerability situations, protecting human life and national riches. Here, we would like to introduce natural disasters occurring in Mongolia, and government preventing policies and as well as problems related to urban development.

Keywords: *disasters, earthquake resistance, urban development, loss reduction*

1. INTRODUCTION

Mongolia is situated in Central Asia with continental climate, hot summers and cold winters. About 40 % of the country is mountainous, 40 % hills (1000-1500m) and the remainder denotation plain. The main agricultural production is animal husbandry, with herds of cattle, sheep, horses, camels, and goats. The population of Mongolia was estimated to be 2.6 million in 2009, with almost 40% of the population in the capital. The most densely populated rural areas are the river valleys in the forest steppe zone. The least populated are the semi desert, desert and mountain taiga zones.

Mongolia has an extreme continental climate. The winter continues long with cold temperature but summer is hot and short. The average summer temperature is +20° C, ranging from +20° C to +36° C. The average winter temperature is -20° C, ranging from -18° C to -40° C. The wind is 1.5-4.5m/s and the average rainfall 200-220 mm in a year.

However, agriculture is a dominant part of the economy, recently mining sector develops rapidly and it makes almost 30% of GDP, 65% of Industrial product and 80% of export product.

2. NATURAL DISASTER IN MONGOLIA

There are several natural disasters in Mongolia as following: meteorological such as blizzard; heavy snow; dust storm "zud"; rain water flood; dibaish flow;snow melt flow; and others such as earthquake; wildfire; drought; and desertification. Top ten Natural disasters which occurred in Mongolia are presented in Table 1.

Table 1 Top ten disaster occurred in Mongolia

Disaster	Date	Killed	Disaster	Date	Affected
Earthquake	2.Dec.1957	1 200	Wind storm	Dec.2000	571 000
Flood	11.Jul.1966	57	Wind storm	Jan.2000	500 000
Wind storm	21.Apr.1990	36	Famine	1990	500 000
Wild fire	Apr.1996	25	Drought	Sep.2000	450 000
Flood	8.Aug.1996	24	Flood	11.Jul.1966	270 000
Wind storm	Dec.2000	19	Wind storm	7.Apr.2001	175 000
Wind storm	7.Apr.2001	16	Wind storm	14.Mar.1993	100 000
Epidemic	Aug.1996	8	Wild fire	Apr.1996	5 061
Wind storm	17.Mar.1993	7	Flood	Dec.2001	4 000
Wind storm	21.Apr.1991	6	Epidemic	Aug.1996	108

Table 2 Natural Disasters from 1982-2008 (UN Report)

Overview	
No of events:	21
No of people killed:	237
Average killed per year:	9
No of people affected:	2,474,446
Average affected per year:	91,646
Economic Damage (US$ X 1,000):	1,913,070
Economic Damage per year (US$ X 1,000):	70,854

2.1Blizzards

Blizzards occur in Mongolia generally between September and May. Duration may be short, just a few hours, or up to 10 days. Number of blizzard days varies between less than two days in the west of the country to between 2 and 8 days in the eastern part of the country and 8-10 days in some mountainous areas. Blizzards can be extremely dangerous with heavy snow and up to 35 m/s wind.

Table 3 Recent blizzard disaster in Mongolia

Year	Place	Fatalities	Livestock lost	Other
Sept.1995	Eastern Mongolia	8	48,000	
May1993	Central Mongolia	17	100,000	
Sept.1993	Central and East	11	5,000	20% potato crop lost
Oct.1992	Central and West	4	500,000	
1988	Dornod, Hentii, Sukhbaatar,Dornogobi	8	10,000	Property damage

The sequence of events in a blizzard disaster begins with the weather turning bad and terminates with harmful events to persons, livestock and crops.

2.2 Heavy snow fall

Heavy snow fall disasters differ from blizzards in that persons are not so much at risk. Damage is primarily caused by livestock being immobilized on the range or in shelters and unable to reach grazing. There are two major aspects of the problem, that of people obtaining supplies if snow lasts a long time, and that of providing fodder for animals which cannot reach pasture due to snow.

On farms there is unlikely to be a large shortage of food. The primary problem is in villages, where direct access to food may not be available if transport is halted for a long time. This is a question of the amount of snow falling, and the length of time it remains. The mean depth for heavy snow falls is typically 10-15 cm, in mountain areas 20-25 cm. Extreme snow falls are up to 1.5 m in mountain areas. Transport becomes difficult with snow falls greater than 40 cm.

When snow is heavy and the snow remains for longer periods, animals begin to weaken and die. Delays in feeding of one day are unlikely to cause significant damage. But following two days without fodder, mortality begins to increase. In winter of 2010, there was heavy snow in whole country and 8 million live stocks could not survive and died

2.3 Earthquake

Earthquakes are quite frequent in some parts of Mongolia. The consequences in villages are generally destruction of housing, roads and bridges. On farms the traditional "GER" houses are very resistant to earthquake damage. During the 20th century, western Mongolia experienced three earthquakes of approximately magnitude 8, and another six events of about magnitude 7. Figure 1 shows locations of these events.

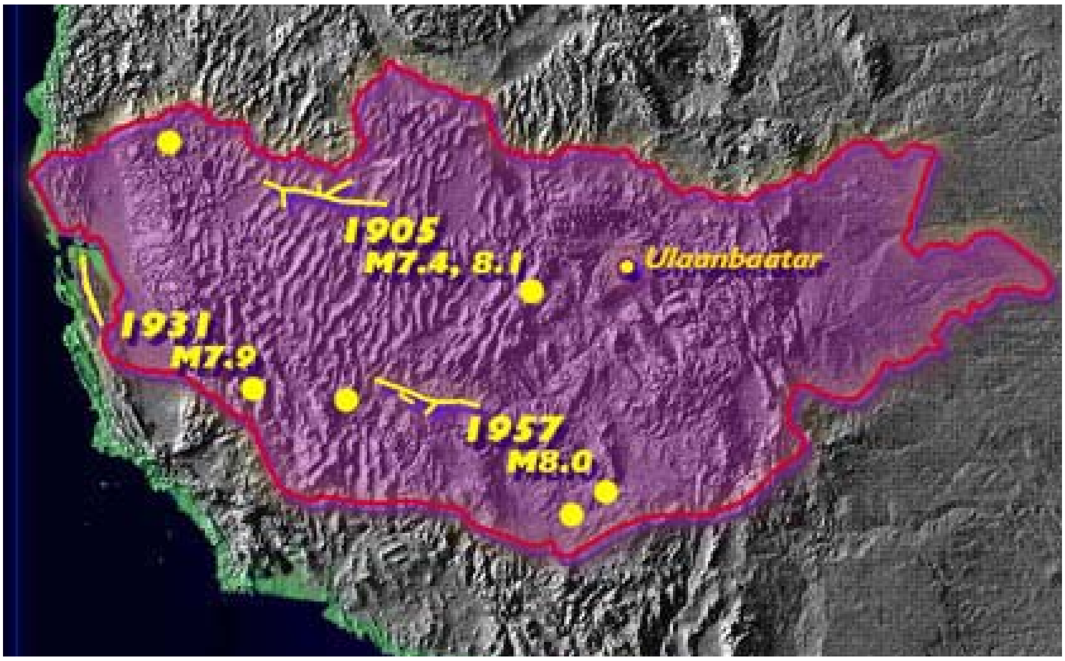

Figure 1 Earthquake locations occurred during the 20^{th} century

3. NATURAL DISASTER REDUCTION

The Government of Mongolia is responsible for all activities related to prevention and mitigation of all types of natural disaster. In 1990, the Government of Mongolia established the State Permanent Emergency Commission (SPEC) in order to coordinate activities among the government agencies against any type of natural disaster.

SPEC has the following functions:

- Preparation of a National Disaster and Calamities Preparedness Plan
- Organization of disaster coordinating down to the ministerial and local government level
- Coordination of relief activities and measures to reduce consequences

- Organization of reconstruction or rehabilitation measures (SPEC has a branch in each aimag and in the large cities).

3.1 State Civil Defence Board

The State Civil Defence Board operates under SPEC in emergency and has the following flmctions:

- duties of civil defence in peace-time
- quick dissemination of information on natural disaster warning and alarm operations
- civil defence education and Training:
- The Civil Defence Board has a central organization u~ Ulaanbaatar, with units at the aimag (province) and sum (district) levels.

3.2 Ministries

Ministries have duties and responsibilities in accordance with their functions to prevent, mitigate and relieve natural hazards, and to educate and build national capacity to combat them. Ministry of Nature and Environment: natural disaster-related data collection and processing, forecasting and warning; dissemination of other operational information to public community, investigation of pollution levels after nuclear and chemical accident.

Ministry of Development disaster-resistance measures: reconstruction or rehabilitation of transport supply.
Ministry of Finance: financing reconstruction and relief measures.
Ministry of Fuel and Energy: fuel and energy supply in emergency.
Ministry of Food and Agriculture: food reserve to meet natural hazards.
Ministry of Health: medical equipment supply; organization of medical service and aid.

3.3 Legislation and natural disaster

In 1990 the Government established the State Permanent Emergency Commission and approved its regulations. In 1993 the Government adopted a resolution on natural disaster prevention measures, coordinating the duties and activities of Central and a local government agencies, and approving the system of transmission for meteorological warnings.

The legislative basis for environmental protection in Mongolia including, emergency and disaster actions, is the MONGOLIAN LAW ON ENVIRONMENTAL PROTECTION, approved on March 30 1995. The following paragraphs are most directly related to emergencies and disasters:
Article 22 Areas of Natural Disasters and Emergencies.

1. The term “areas of natural disasters and emergencies” means an area which is affected by adverse impacts or hazardous changes of the environment resulting from human activities or natural evolution, which may have detrimental impacts on the environment, human, animals, wildlife, plants, and their genefunds.

2. The Government shall establish boundaries for areas of natural disaster and emergencies upon consultation with the Central State Administrative Organization in charge of nature and environment.

3. The Central State Administrative Organization in charge of nature and environment, Civil Defence Board, Governors of all levels and other concerned organizations shall jointly take measures on prevention and mitigation of natural disasters and emergency, elimination of adverse impacts, rehabilitation of nature and environment, and restoration of natural resources.

4. All costs for mitigating natural disasters and emergencies shall be allocated from the State budget. After the investigation of real cause the guilty party or citizens shall be assessed for the full compensation of any damages and losses.
Article 23. Environmental Protection in State of Emergency

Any measures with respect to mitigation of natural disaster, elimination of adverse impacts, and preservation of the environment and its natural resources undertaken within an area affected by State emergency shall be carried out pursuant to the rationale for, and procedures stipulated by the State Emergency Laws as provided by the Constitution of Mongolia.

The Civil Defence Law, approved in May 1995, officially included set of measures aimed at preventing, and safeguarding the people from natural disaster, eradicating the damage hitherto incurred by the population, and training in these aspects.

4. CONCLUSIONS

1. Natural disasters are very sensitive issues for Mongolia, especially from the economic point of view. Losses to herds, flocks and crops annually affect a very significant part of the country.
2. The high frequency of natural disasters and their extent presents a serious constraint which delays development of the country.
3. Natural disasters cause significant loss of life, and of property.
4. The sheep flocks, cattle and horse herds of Mongolia represent a large portion of the wealth of the nation, and are an essential part of the livelihood of most mongolians.
5. The disasters contributing to losses of herds and flocks are heavy snow, blizzards, dust storms, drought, and floods.

EVALUATION OF FIRE FIGHTING SYSTEM AT HIGH-RISE BUILDINGS IN DHAKA CITY

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ABSTRACT

Incident associated with fire is a common phenomenon in Bangladesh especially at densely populated Dhaka city. Being the hub of all economic activities this city provokes people to live here and compels to construct high rise building. Fire is becoming an unmanageable threat particularly in high rise buildings mostly constructed violating the national building code of Bangladesh. In Dhaka, buildings are closely spaced such that if one building accidentally catches fire, it is obvious that building beside the affected one may also catch fire. Recently some grievous fire incidence has been experienced and fire engulfed lot of lives and properties. The main causes behind the colossal losses were inadequate fire fighting equipments in buildings and lack of awareness about fire safety. These stimulate to conduct a detailed study on fire fighting system in high rise buildings of Dhaka city. For this study a questionnaire survey has been conducted to check the existing condition of fire fighting system, awareness level and residents' evacuation plan. To have overall scenario regarding fire safety, 2.5% buildings out of 2150 high rise buildings in Dhaka city have been surveyed from 9 zones (Department of Fire Service and Civil Defense divided Dhaka City into 12 zones) and most of them are above 8 storied. This paper have examined the existing condition of fire fighting system including protection and detection system, precautionary arrangement in and around high rise buildings, occupants' awareness level and evacuation plan during fire break out and assessment of these systems with Bangladesh National Building Code (BNBC) rules in terms of Total Score (TS). This paper also has studied how far high-rise buildings are practicing these systems, main causes of fire hazard, obstacles to evacuation, rescue operation and fire control.

Keywords: fire, high-rise buildings, fire fighting system, awareness level, evacuation plan

1. BACKGROUND

A fire hazard is any situation in which there is a greater than normal risk of harm to people or property due to fire. Urban fires have devastating impact on communities. Unplanned urbanization and rapid industrialization are the major causes of huge number of fire related accidents in Dhaka city and increase the vulnerability of the country's major population and economic centers. Dense building concentrations, narrow roads, flammable building materials and electrical system as well as the lack of resources to raise awareness and response skills have resulted in a growing risk of large scale, multiple structure fires.

Fire incidents are very common in Dhaka city, especially in relatively densely populated areas. The damage of property and loss of human life are intensified by different factors. The extent of loss due to fire incidents has an increasing trend and it is shown in Figure 1.

Figure 1: Extent of losses due to fire hazards in different years

A developing country like Bangladesh cannot afford the huge amount of loss caused by fire accidents every year. Moreover, fire incidents in shops, industrial and commercial buildings cause heavy toll of life and property. The fire incidents are on an increase due to lack of awareness, almost no feeling for following safety measures and practicing fire fighting drills, violation of building codes and non-compliance with the Fire fighting and Extinguishing Law (BFSCD, 2003).

Some recent flagitious fire incidents in Dhaka city have stimulated a detailed study on high rise buildings about fire safety and awareness. This study depicts an overview on overall condition of existing fire fighting system and on awareness level among the occupants of high rise buildings in Dhaka city.

2. MAJOR CAUSES OF FIRE INCIDENT IN BANGLADESH

Common Causes of fire are smoking, welding or cutting operation and use of blow lamps, sparks from power unit, short circuit and over loading of electrical current, children playing with crackers, ignition by chemical action/spontaneous combustion, gross carelessness, malicious, deliberate during riot or strike, lightening, earthquake etc (see Figure 2). Fire at garments is very common in Bangladesh, major fire incidents take place due to unplanned construction of buildings being used by garment factory owners. Most of the buildings did not follow the building code and lacked arrangements for alternative staircases and emergency exits and firefighting equipment. Keeping collapsible gates under lock and key in the name of security is the main cause of increases casualties in the incidents. According to the statistics, the major accidents occurred due to electric shot circuits. The highest 3334 accidents took place in 2006, 2787 in 2005 and 2522 in 2004 (The New Age, February 10, 2009) (see Figure 3).

High-rise buildings now being constructed in different parts of the city is in lack of the minimum safety features and endangers both adjoining structures and public thoroughfares. Many of the high-rises have been constructed without proper planning, ensuring adequate structural strength, without taking the proper safety measures and considering environmental factors.

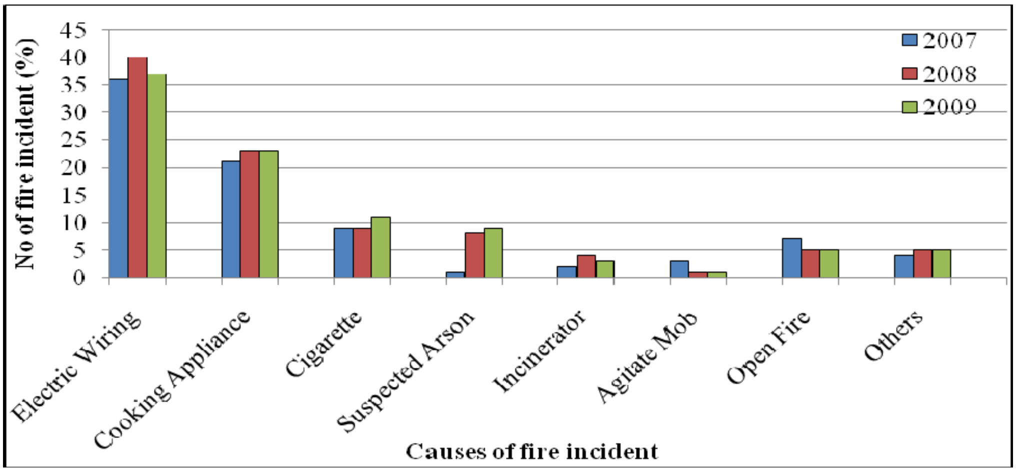


Figure 2: Causes of fire incident in Bangladesh

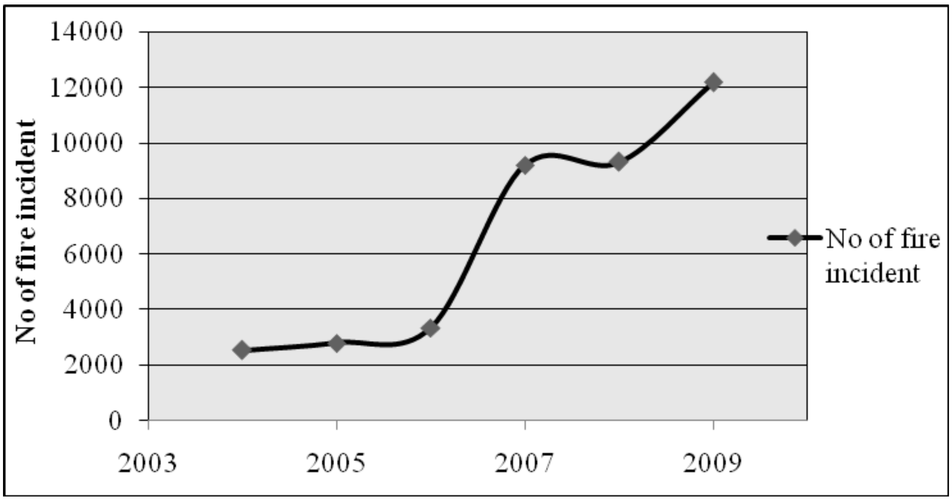


Figure 3: Trends of fire incident in Bangladesh (The New Age, 2009)

3. RECENT SEVERE FIRE INCIDENTS IN BANGLADESH

In Bangladesh, especially in Dhaka and Chittagong city, fire is becoming an unmanageable threat particularly in high rise buildings mostly constructed violating the national building code. Various incidences of major occurrence of fires in different type buildings are given below.

Fire in BSEC Bhaban
A devastating fire broke out at the Bangladesh Steel and Engineering Corporation (BSEC) Bhaban in the capital on 26 February 2007. Several witnesses said the fire originated from electric oven; while some others said it was sourced from electric short-circuit. There were fire extinguishers on almost all the floors but none dared to use them. This building's neither has any emergency exits nor a sufficient number of fire-fighting equipment and operators to use them during fire. There was also no fire lift but a switched off lift. Acute shortage of water and inadequate equipment hampered the rescue operation. Three persons were killed and more than 100 injured in this incidence. NTV, RTV offices totally burnt and went off air. (www.thedaily star.net)

Photograph 1: Smoke billows out of the BSEC building and victims trapped in the fire that caught the building come down a ladder

Bashundhara Fire
On 13 March 2009, Friday at about 1:45pm, a hell fire engulfed the upper levels of 20 storey office cum shopping centre known as Bashundhara City Complex at Panthopath, Dhaka killing 7 and injured 20 people. Though the building was equipped with sufficient fire detecting, suppressing, and evacuating systems but they were useless during the fire. From the fire Brigade sources it was known that complex's water reservoir remained empty, the hydrants were useless as there was no water in the tank. Due to faulty fire fighting system, the fighters of the building didn't care about those warnings though the fire alarm on the 18th floor, where the fire broke out first, gave false alarm 18 times during the same period.

Terrible fire incident in Nimtoli at Old Dhaka

An overwhelming fire broke out in the densely-populated part of Old Dhaka city at Nimtoli. Fire devoured at least 117 people and causing injury about hundreds of people at 3rd June, 2010. Most of the affected peoples were women and children. Initially it was thought that explosion of two transformers at Nimtoli started the fire but later it has been known the fire originated from an oil stove and spread to the chemical warehouses nearby and resulted high casualty figures and damages. It is common scenario in Old Dhaka that most of the buildings have small factories i.e. chemical, plastic, rubber etc., and ware house and food shops up to second floor of the residential building. In Old Dhaka no house is equipped with fire fighting equipments like extinguisher, hose pipe etc. They don't have sufficient width of staircase let alone the emergency exit (www.thedaily star.net).

Photograph 2: Fire engulfing the Bashundhara City market

Photograph 3: Fire engulfing the Nimtoli area

Fire in KTS textile mills

Ninety one people were killed in a fire in KTS textile mill, Chittagong, February 23, 2006. At least 500 workers were inside the mill when the fire broke out. Most of the survivors had to jump from windows as the only exit from the factory was reportedly locked when the fire broke out late on a Thursday night. Most of the victims were women, trapped by the flames or suffocated from smoke inhalation. The fire might have been caused by an electrical short circuit. The explosion of a boiler escalated the blaze (www.thedaily star.net).

After analyzing the past incidents and accidents, some terrible facts are revealed. In most cases imperfect arrangements and training of the safety equipments such as fire alarm, smoke alarm, fire extinguishers, water supply system etc., lack of proper exit route to reach the place of safety ,routes are blocked by different materials ,lack of signage for escape route and emergency lighting, adequate doors as well as adequate staircases are not provided to aid quick exit , fire exit or emergency staircase lacks proper maintenance , lack of proper exit route to reach the place of safety and most importantly lack of awareness among the residents, workers and the owners are the main causes of heavy toll of life and property.

4. EXISTING CONDITION OF FIRE FIGHTING SYSTEM IN DHAKA CITY

For the evaluation of fire fighting system in Dhaka city a questionnaire survey was conducted to assess the existing condition of total fire fighting system, awareness level of the respondent and their evacuation plan during fire catch up. To have overall scenario regarding fire safety, 2.5% buildings (includes residential, commercial, garments and institutional etc.) of 2150 (according to Dhaka City Corporation, total no. of high rise building) has been surveyed from 9 zones (Department of Fire Service and Civil Defense divided Dhaka City into 12 zones) and most of them are above 8 storied (see Map1). Figure 4 and Figure 5 show number of study buildings and existing use of the buildings in percentage respectively. Another objective of this study was to determine the awareness level of occupants of the surveyed buildings. 64% and 80% of total respondents know about earthquake and fire respectively but only a little number of respondents has any evacuation plan about fire incidents.

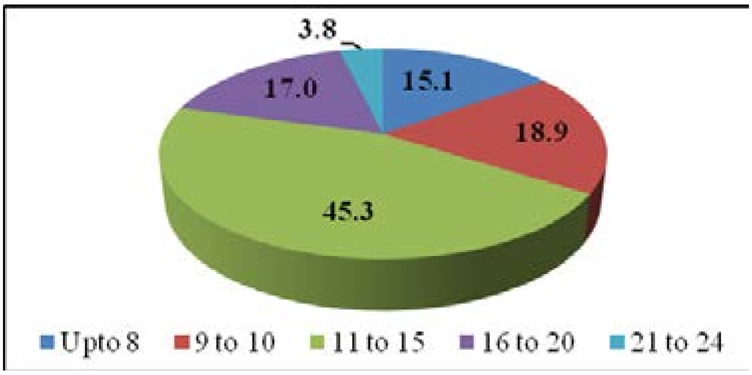


Figure 4: Number of study buildings by storey (in %)

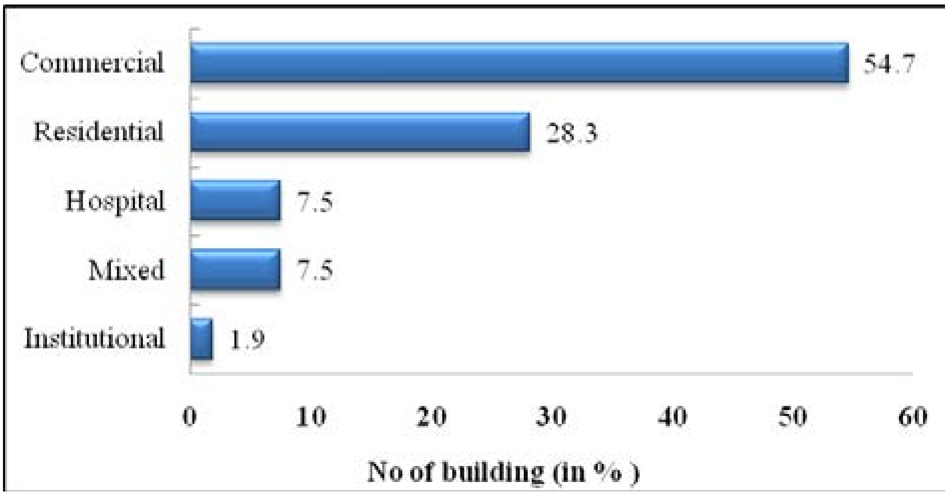
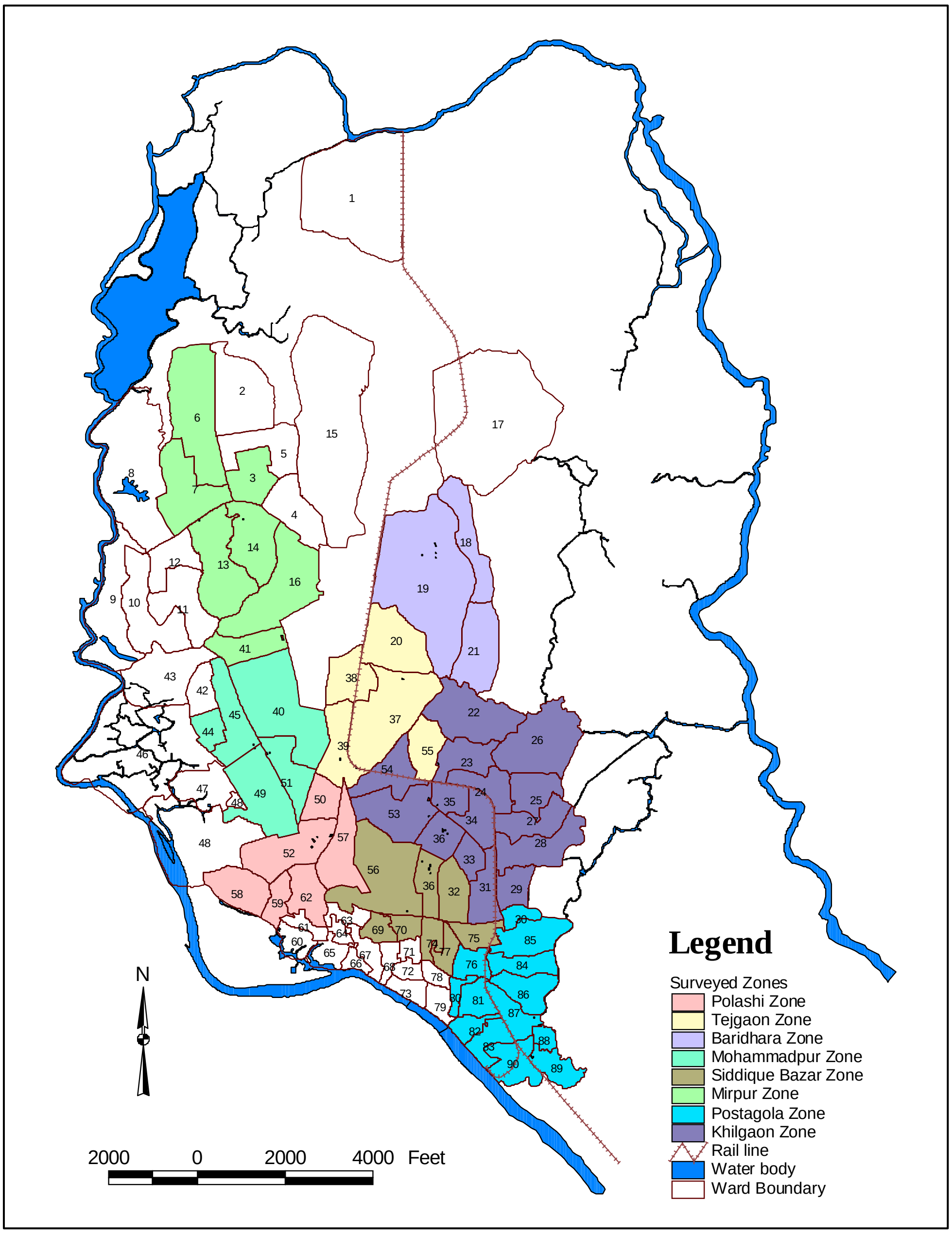


Figure 5: Use type of high rise building

For covering the all details, fire fighting equipments are divided into four parts i.e. *fire fighting and fire protection* system which includes *water-based system* and *dry system*, *precautionary arrangement*, *detection and alarm system*, and *evacuation, rescue and salvation system*. All of these four parts comprise of several components.

4.1 Evaluation of fire fighting and protection system

Fire fighting and fire protection system consists two sub-system i.e. *water –based system* and *dry system*. *Water-based system* of fire fighting and fire protection include availability of standpipe and hose system, sprinkler system, water supply sources to standpipe, capacity of underground and roof gravity tank, details of fire pump and jockey pump, and availability of *Siamese* connection. Buildings should have underground reservoir of 50000 gallons and overhead reservoir of 25000 gallons (BNBC, 1993).



Map 1: Study Area within Dhaka City

The survey has shown that 74% and 96 % of total buildings are undersized for underground and overhead reservoir respectively. From questionnaire survey it has been found that out of 53 buildings, 24 have standpipe connection but not all of them were in work. After a detail investigation about standpipe which includes number, diameters of standpipe, class of standpipe (class I, class II, class III), only 7 buildings reflected a good condition whereas 15 buildings showed very bad condition. Among 24 buildings having standpipe, only 10 buildings have fire pumps and only 5 of these are in good condition i.e. number and pressure of pump are adequate. Only 2 commercial buildings have water sprinkler system. In BNBC (1993), sprinklers, hose reel and hose pipe are strongly recommended to install in high-rise buildings as safety measure. Photograph 4, 5 and 6 show fire pump, jockey pump and hose reel with standpipe in a commercial building respectively.

Photograph 4: Fire pump in commercial building

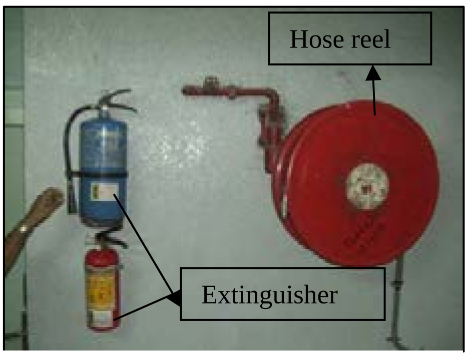
Photograph 5: Jockey pump in commercial building

Photograph 6: Hose reel with stand pipe in commercial building

Dry system includes fire lift and portable fire extinguisher in floor and basement.

Fire extinguisher system with combination of carbon-dioxide extinguisher, dry chemical extinguisher is available in 53% buildings. However, it has been observed that most of the buildings' fire extinguishers are not in required quantity and they are out of date. As the surveyed buildings are high rise structures, it is mandatory to set up fire extinguisher system to control the fire incidents initially. Most of the buildings have no hose pipe or hose reel system.

Photograph 7: Blocked hose pipe



Photograph 8: Perfect position of hose reel with fire extinguisher

4.2 Evaluation of precautionary arrangements

Precautionary arrangement is very important for minimizing the loss of lives and properties. It comprises heat and smoke vent, four hours rated door of substation and 2 hours rated wall of substation. From the questionnaire survey it has found that only 10 buildings have 4 hours rated door and 2 hours rated wall of substation. Number of building having smoke and heat vent is only one.

4.3 Evaluation of fire detection and alarm system

Detection and alarm system includes availability of fire alarm (automatic or manual), smoke and heat detector, Public Address (PA) system and existence of emergency light in stair case and corridor. Among the studied buildings none of them have flame detector. On the other hand, it has been observed that 25% buildings and only 4% buildings have smoke detector and heat detector respectively. In addition, 36% buildings have alarm system and among them 30% have public address (PA) system (see Figure 6).

From observation, it is evident that fire fighting detectors and equipments are seldom tested and checked as routine work.

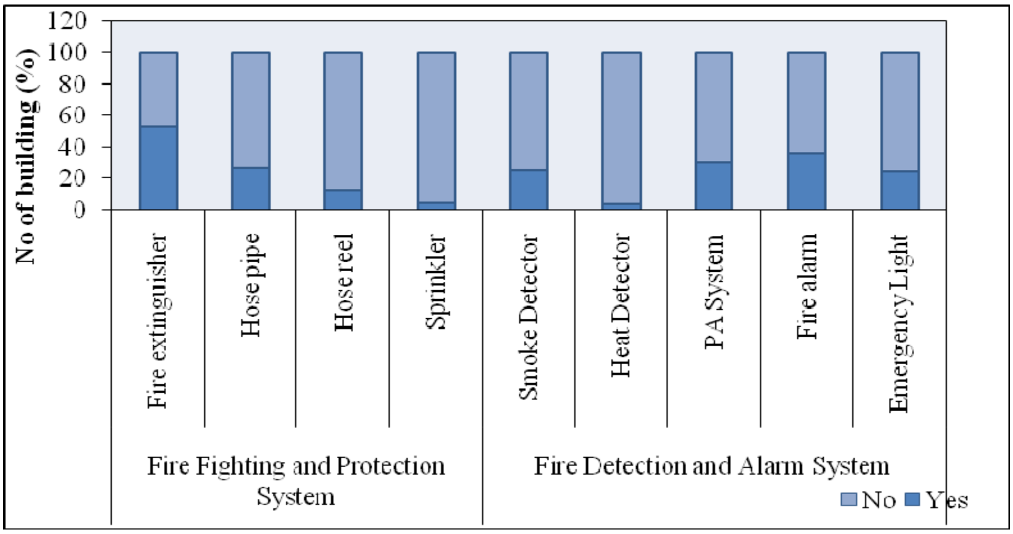


Figure 6: Overall scenario of fire fighting system in Dhaka City

Photograph 9: Fire alarm and fire bell

Photograph 10: Smoke detector

4.4 Evaluation of evacuation, rescue and salvation system

Evacuation, rescue and salvation system consists of total number of stair and emergency staircase, width of normal and emergency stair, availability of fire refuge area, trained personnel, width of front road, evacuation plan of the inmates of the buildings and practice of fire drill. According to Bangladesh Fire Service and Civil Defense (BFSCD, 2003), Minimum width of frontal road should be 30 ft for free moving of fire vehicle. Survey shows that a considerably large number of buildings i.e. 27.5% of surveyed building have inadequate width of approach road (less than 30ft) for fire engines to reach the building (see Figure 7).

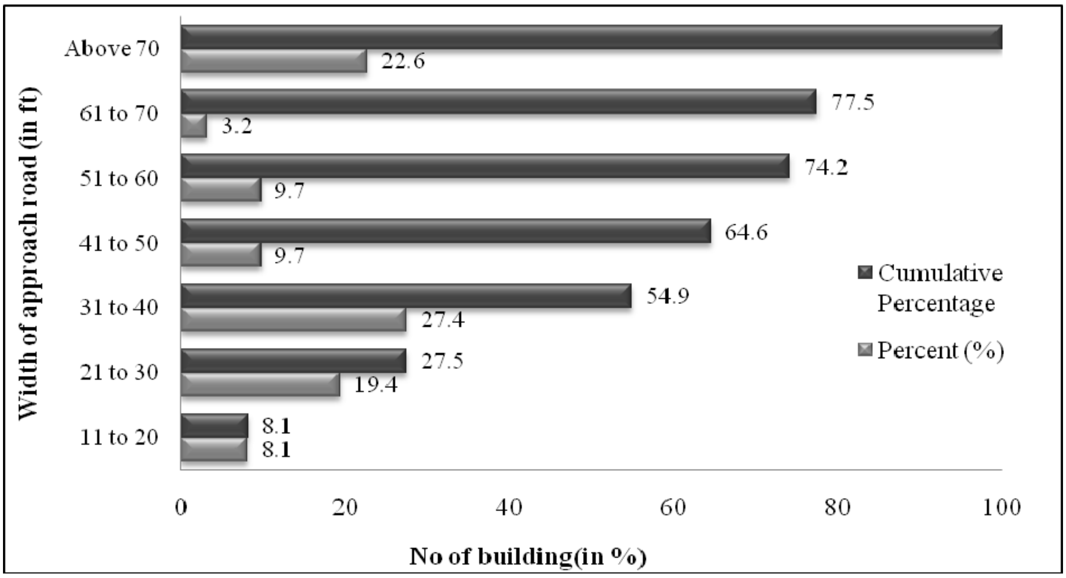


Figure 7: Width of approach road

Photograph 11: Narrow emergency stair case in a residential building

Photograph 12: Blocked emergency stair case in a commercial building

...s dor... are provided improperly and inadequately which poses a threat to the evacuation. In most of the cases escape routes remain blocked (see Photographs 11 and 12).

Among all the surveyed buildings, only 11 buildings have trained personnel and only 16 buildings which include garments and commercial building perform fire drill regularly. Most surveyed garments workers were trained by Bangladesh Garment Manufacturers and Exporters Association (BGMEA). Usually they provide lectures, taken exam and lastly done evacuation drill in the premises of garments. In the surveyed commercial buildings which have trained personnel got training related to operation of hose reel and fire extinguisher and evacuation drill from Bangladesh Fire Service and Civil Defense (BFSCD, 2003). Mainly security guard and few care takers of the building have this training. The respondents were asked about their evacuation plan during the fire incidence but only few people have their evacuation plan. Evacuation plan consists use of firefighting equipment what they have, escape from the building through emergency exit and taking shelter in ground floor or any available open space adjacent to the building.

5. SCORING OF THE SURVEYED BUILDINGS

One of the main purposes of this study was to provide score to the surveyed building based on their existing fire fighting equipments. For providing score, data collected from field survey were compared to the provision of Bangladesh National Building Code (BNBC, 1993) and that of Bangladesh Fire Service and Civil Defense (BFSCD, 2003). 0-10 scale was selected to provide an initial rank to the different components of fire fighting equipments. Then from case studies and experts opinion, weights were assigned to each of the four parts of firefighting equipment. The process of obtaining the score is given below:

Total Score (TS) = weight for water-based system *(acquired number in scale of 0-10) + weight for dry system *(acquired number in scale of 0-10) + weight for precautionary arrangement *(acquired number in scale of 0-10) + weight for detection and alarm system *(acquired number in scale of 0-10) + weight for evacuation, rescue and salvation system *(acquired number in scale of 0-10). According to the experts, the weight assigned for water-based system is 12, for dry system is 8, for precautionary arrangement is 25, for detection and alarm system is 30 and for evacuation, rescue and alarm system is 25. For evaluating the condition of Buildings, all buildings are divided into 5 category based on their in-built fire fighting system. These categories are given below,

Table1: Building Condition Based on Total Score

Building Condition	Total Score(TS)
Low	Below 20
Moderately Low	21-40
Moderate	41-60
Moderately High	61-75
High	75-100

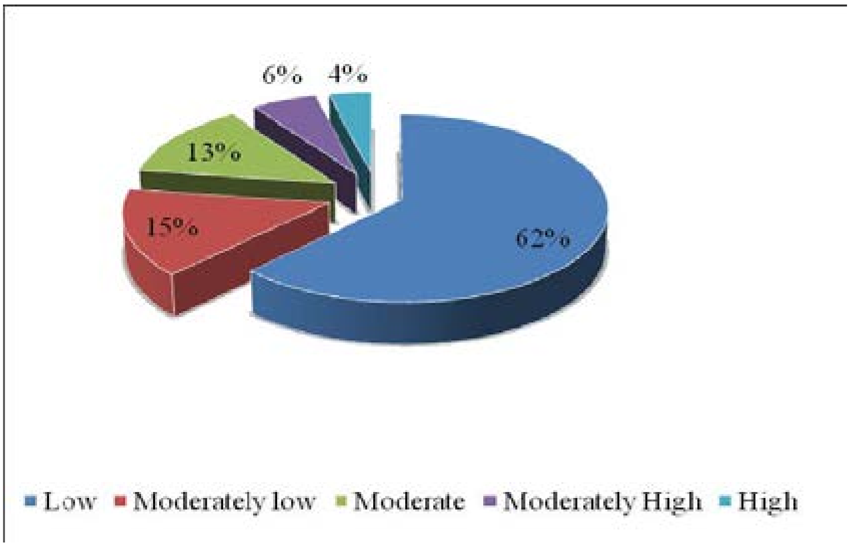


Figure 8: Quantitative diagram of present condition of building at Dhaka city

The pie chart portrays that most of the buildings (62%) lacks in-built fire fighting equipments whereas the number of buildings which are highly equipped with in-built fire fighting system are significantly low.

6. CONCLUSIONS

After analyzing a considerable amount of highrise building information in Dhaka city, it can be said that the overall condition of buildings are not suitable for fire fighting. Only a small number of buildings have moderate to good status for fire fighting. This study was not conducted on a large number of building samples. Although the sample size was small, it represents the miserable condition of Dhaka city buildings to fire hazards. For improving the condition, all buildings should follow the provision provided by Bangladesh National Building Code and Bangladesh Fire Service and Civil Defense during construction of building. To ensure that, authority should be strict and need to take action against those violating the concerned laws. The good practices of fire hazard prevention in the building codes of other countries need to be studied and adopted according to Bangladesh's context. In addition to law enforcement, to create public awareness, workshops and seminars may be arranged. Electronic and printing media can play an important role for increasing awareness. A pragmatic fire safety plan may be developed for all the buildings with the help of Bangladesh Fire Service department.

REFERENCES

Bangladesh National Building Code (BNBC), 1993, published by HBRI-BIDS.
Bangladesh Fire Service and Civil Defense (BFSCD), 2003, Fire Fighting & Extinguishing Law.
www.thedaily star.net accessed on June 2, 2010.

The New Age (2009) accessed on June 2, 2010.

Experimental study on the turbulent characteristics in thermal buoyant plume of urban fire

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ABSTRACT

It is very important to investigate the turbulent characteristics in the thermal buoyant plume of urban fire in the present of wind to understand the urban fire spread risk. In this study, the thermal buoyant plume of urban fire is presented by helium, and turbulent physical statistics parameters have been measured in a wind tunnel in windy conditions. Hazard gas is presented by ethylene which is mixed in the helium. The turbulent physical statistics parameters including average velocity, turbulent fluctuation of velocity, Reynolds stress, turbulent kinetic energy, average pollutant concentration and turbulent fluctuation of pollutant concentration are measured. The characteristics of these turbulent physical statistics parameters are investigated and the effects of buoyancy on these parameters are analyzed.

Keywords: thermal buoyant plume, urban fire, turbulent characteristics, helium

1. INTRODUCTION

In the present of wind, the thermal buoyant plume induced by urban fire will give large heat flux to the neighboring buildings and increase the risk of fire spread. Furthermore, firebrands and hazard gases generated from the fire will be spread by the thermal buoyant plume and enlarge the fire spread and pollutant areas. Therefore, it is very important to investigate the turbulent characteristics in the thermal buoyant plume of urban fire in the present of wind.

There are many studies on the measurement of temperature of thermal flow (Hayashi et al, 2002; Imamura et al, 2003), however, few study has been done on the measurement of the turbulent characteristics in the present of wind. In this study, the thermal buoyant plume of urban fire is presented by helium, and turbulent physical statistics parameters have been measured in a wind tunnel in windy conditions. Hazard gas is presented by ethylene which is mixed in the helium. The Froude number is adjusted by the inflow wind speed, and two Froude number cases have been conducted. The turbulent physical statistics parameters include average velocity, turbulent fluctuation of velocity, Reynolds stress, turbulent kinetic energy, average pollutant concentration and turbulent fluctuation of pollutant concentration. The characteristics of these turbulent physical statistics parameters are investigated and the effects of buoyancy on these parameters are analyzed.

2. EXPERIMENT OVERVIEW

(1) Wind Tunnel
The used wind tunnel is a boundary layer wind tunnel. The wind tunnel has 13- m long, 2.2- m wide, and 1.8- m high test section. A schematic diagram illustration of the wind tunnel is illustrated in Figure 1. The simulated boundary layer was generated with the aid of homogeneously distributed roughness elements mounted on the tunnel floor and by vortex generators installed at the test section inlet (ACE, 1999). The spires as well as the size and arrangement of the roughness elements controlled the properties of the induced boundary layer.

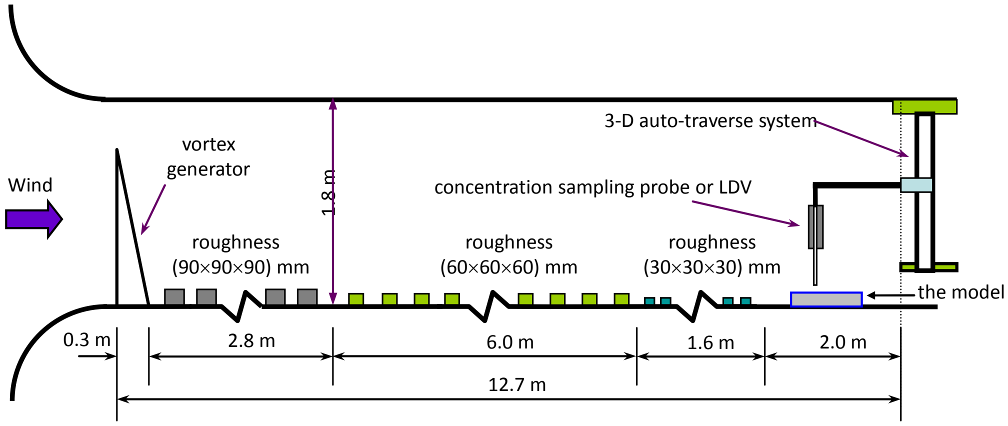

Figure 1 Schematic diagram illustration of the wind tunnel

(2) Urban model
Figure 2 shows the urban model. And the scale is 1:200. A modeled urban area is set here. A building is assumed to be on fire. The thermal plume is presented by helium which is emitted from the roof of the building. Ethylene is mixed in helium to present hazard gases in the fire.

(3) Experimental cases
Table 1 shows the test case. Two actual situations, that the average wind speed at the height of 10m (building height) from the ground are 4m / s and 8m / s, are assumed. The fire plume temperature is 800℃, and the outdoor temperature is 20℃. Froude number ($Fr = (\Delta\rho/\rho)Dg/U^2$) of the wind tunnel test is arranged to match the actual Froude number. In order to simulate the buoyant plume, according to the reference (Mell et al, 1996), the emission rate of the gas mixture of helium and ethylene is set to be W = 0.15m / s and the gas mixture is completely exhausted from the building roof. Then, considering that the explosion limit of ethylene, the ratio is set to be 0.34%.

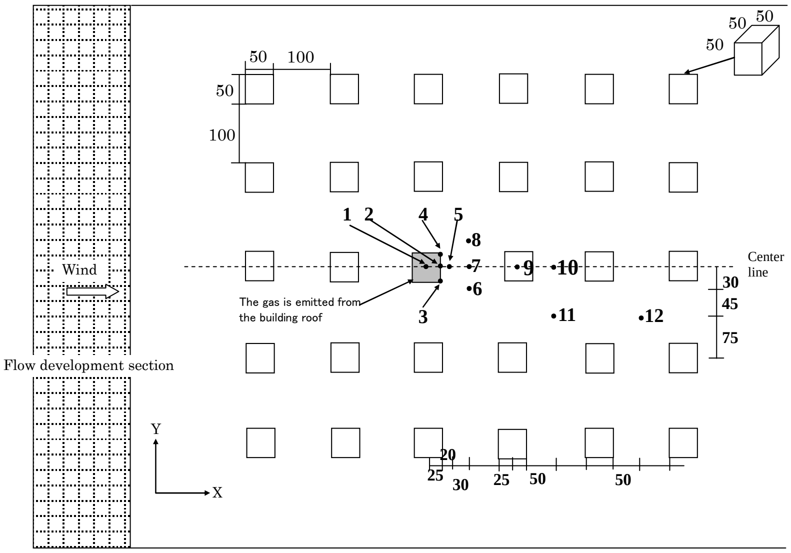

Figure 2: The city model and measurement points

Table 1: Experimental cases

Experimental cases	**Wind speed at 10m height(actual situation)**	**Wind speed at 5cm height(model)**	**Froude number**
Case 1	4m/s	0.31m/s	4.37
Case 2	8m/s	0.62m/s	1.09

(4) Measurement item
The average velocity, turbulent fluctuation of velocity, Reynolds stress, turbulent kinetic energy, average pollutant concentration and turbulent fluctuation of pollutant concentration have been measured.

(5) Measuring instrument
The wind speed is measured by 3D Laser Doppler Velocimetry (LDV). Measurement time is set to 120 seconds. FID (Flame Ionization Detector) hydrocarbon concentration meter (Cambustion, THC-2A) which has high response is used to measure the pollutant concentration. The response of the concentration sensor of FID is 100Hz, approximately.

(6) Measurement points
Measurement points are shown in Figure 2. In the vertical direction, the points were set at an interval of 10mm or 20mm over the ground or building roof.

(7) Approaching wind flow
To reproduce the natural wind, vortex generator and the roughness are arranged in the inlet part of the wind tunnel. Figure 3 shows the average velocity and turbulence intensity of the wind flow. The approaching wind flow profile is U $Z^{1/3}$ approximately.

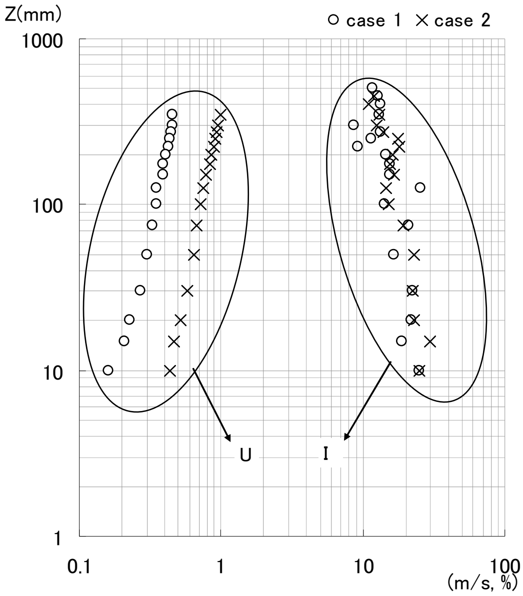

Figure 3: Approaching wind profile

3. EXPERIMENT RESULTS

The figures (Fig.4-11) show experimental results. The velocity has been standardized by U_H which is the velocity of the inflow at the building height.

3.1 Vertical distribution of U and $\sqrt{u'^2}$ (Figure 4, 5)

Looking at the vertical distribution of U, there was no significant difference of the non-dimensional U in Case 1 and Case 2. It is understood that the buoyancy has no large effect on U. The velocity U in the canyons between buildings (point 7, 10) is almost zero. The distribution of $\sqrt{u'^2}$ is slightly larger.

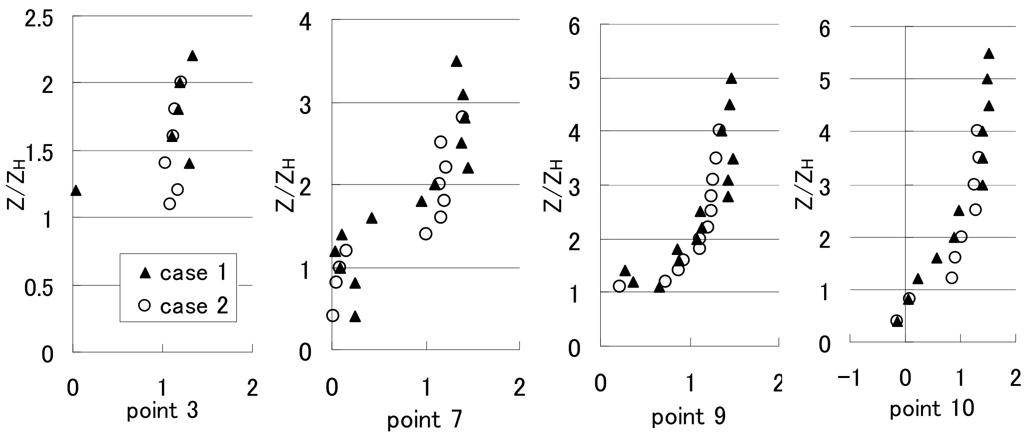

Figure 4: Vertical distribution of U (U/U_H)

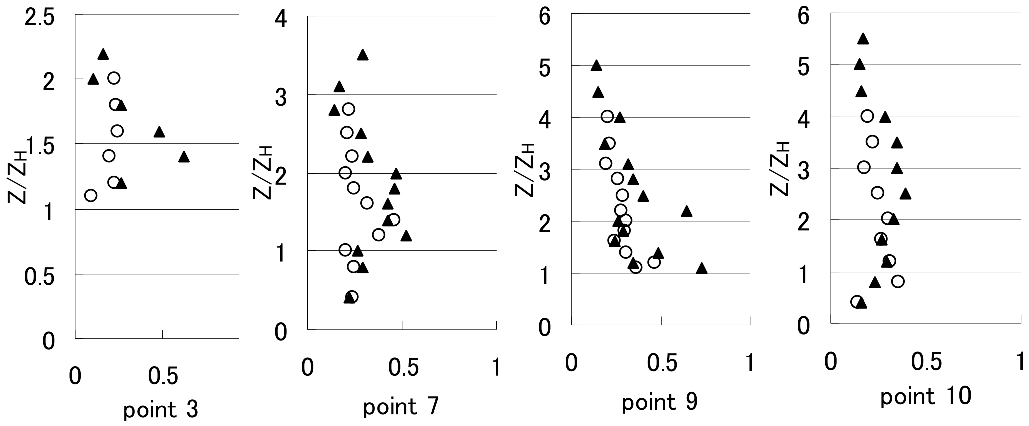

Figure 5: Vertical distribution of $\sqrt{u'^2}$ ($\sqrt{u'^2}/U_H$)

3.2 Vertical distribution of W and $\sqrt{w'^2}$ (Figure 6, 7)

It is found that upward flow occurs at each point which shows the buoyancy effect. In Case 1 there is a stronger upward flow. In case 2, it should be considered that because of the strong wind inflow, the upward flow is suppressed. There are peaks in Case 1. In Case 2 there is upward flow near the outlet, and the upward flow decreases to almost zero after point 7. It is shown that the fluctuation of velocity is more significant in Case 1 and W shows a peak approximately at the same height as the peak of the concentration (shown in Figure 10). This is considered to be due to the positive contribution of the buoyancy production term $-2g\beta\langle w'c'\rangle$ in the transport equation of $\sqrt{w'^2}$.

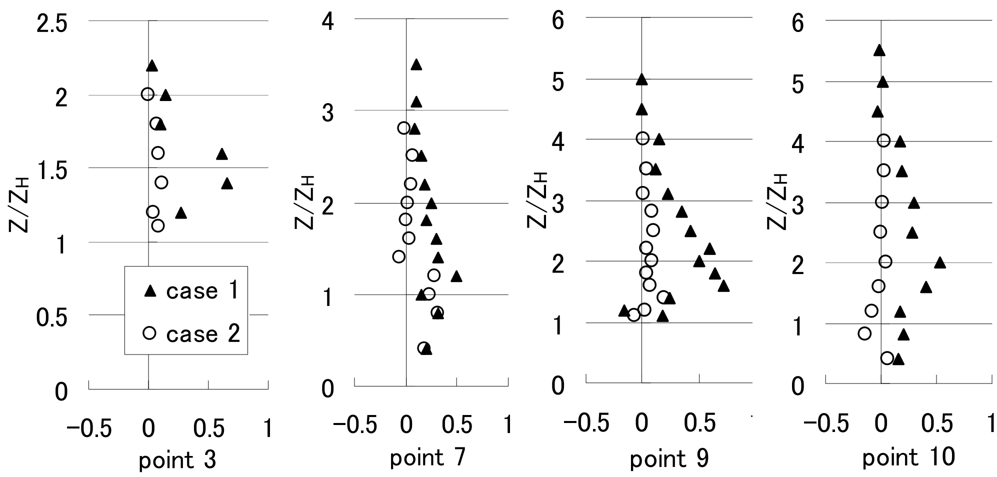

Figure 6: Vertical distribution of W (W /U_H)

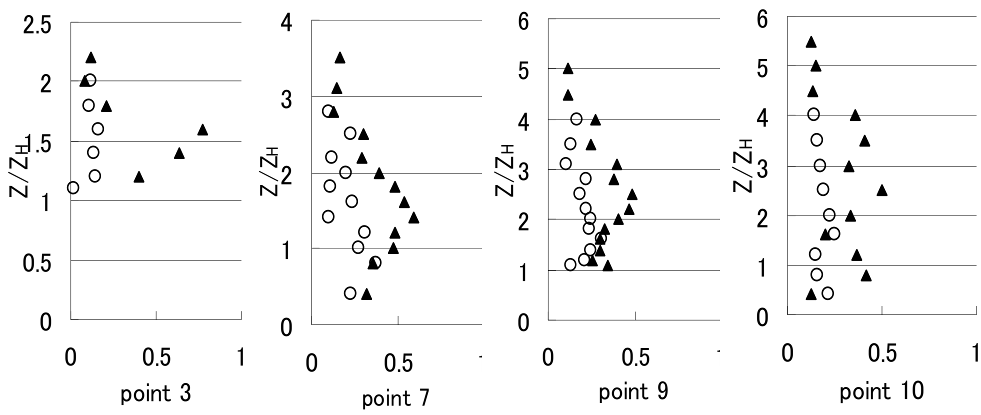

Figure 7: Vertical distribution of $\sqrt{\overline{w'^2}}$ ($\sqrt{\overline{w'^2}}$ $/U_H$)

3.3 Vertical distribution of $-\overline{u'w'}$ and k (Figure 8, 9)

At point 7 and 10, the Reynolds stress is positive, while near the roof surface (point 9 and 3), it shows a negative value. This is due to the effect of separation at the building roof. The Reynolds stress decreases along the downwind direction. Peaks are shown for the turbulent kinetic energy, which are consistent well with the distribution of $\sqrt{\overline{u'^2}}$ and $\sqrt{\overline{w'^2}}$. The large fluctuation in Case 1 is considered to be due to the large buoyancy production.

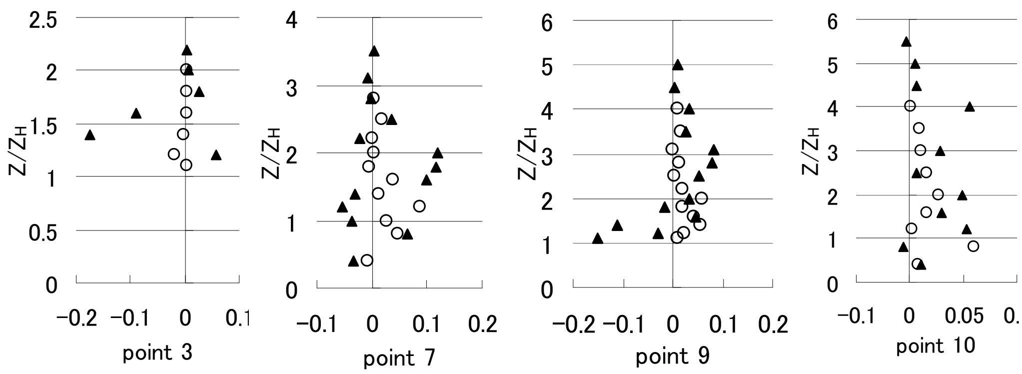

Figure 8: Vertical distribution of $-\overline{u'w'}$ ($-\overline{u'w'}$ $/U_H^2$)

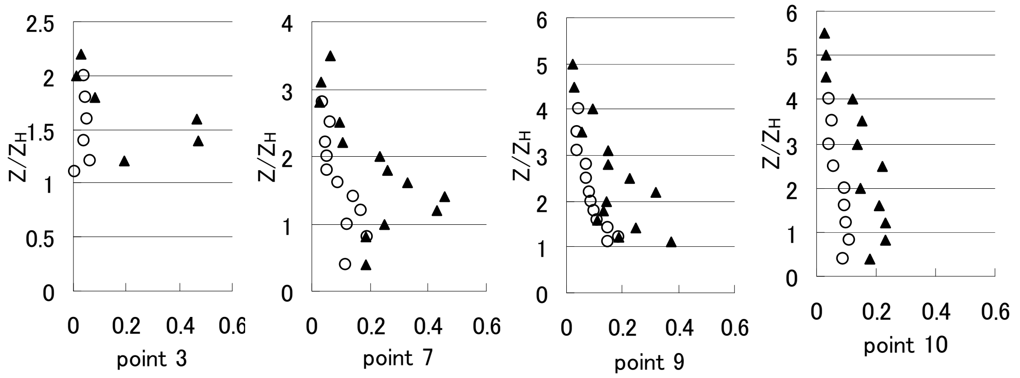

Figure 9: Vertical distribution of k (k $/U_H^2$)

3.4 Vertical distribution of concentration and turbulent fluctuation of concentration (Figure 10, 11)

Urban air pollution and gas are transported (advection and diffusion) by the buoyancy flow and urban wind in the downwind direction. The pollutant concentration is high near the roof surface, while the concentration decreases along the downwind direction. Away from the outlet, peaks are clearly shown. The faster the approaching wind flow, the lower the peak height is. Above the peak position, Case 1 shows a higher concentration, while below the peak, the concentration in Case 2 is higher. This means that the advection and diffusion of the gas are suppressed. Along the downwind direction, the height of the peak rises. The distribution of the average concentration and the distribution of concentration fluctuation are well consistent. It is shown that at the position with high average concentration and high concentration gradient, the concentration fluctuation increases. The average concentration and the concentration fluctuation are consistent with the maximum height, which is considered to be reasonable due to the production term $-2\langle u_i'c'\rangle(\partial\langle c\rangle/\partial x_i)$ in the transport equation of c'^2.

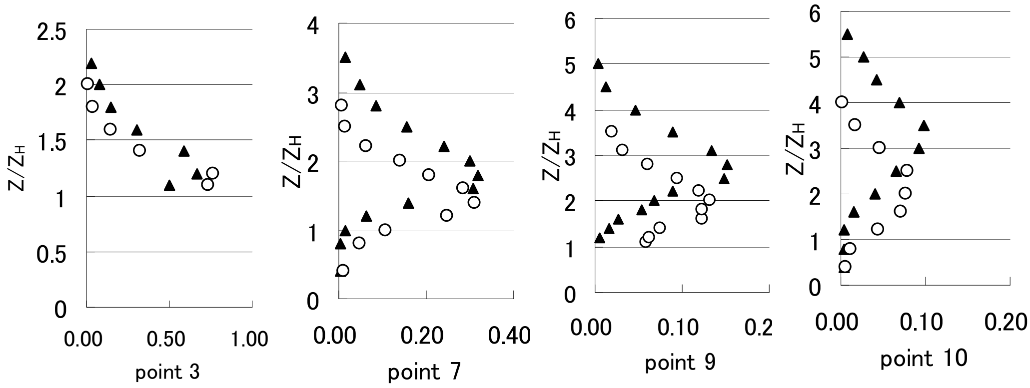

Figure 10: Vertical distribution of concentration (c/c_{max})

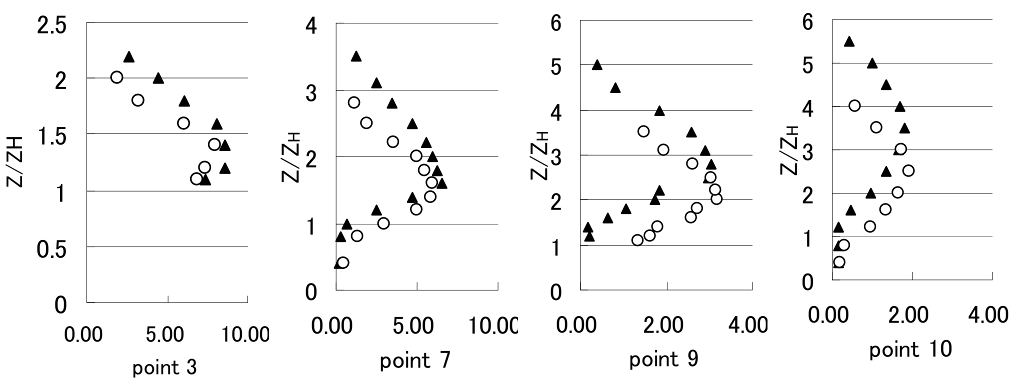

Figure 11: Vertical distribution of fluctuation of concentration ($\sqrt{c'^2}/c_{max}$)

4. SUMMARY

The thermal buoyant plume induced by urban fire were simulated using a gas mixture of helium and ethylene. The average velocity, turbulent fluctuation of velocity, Reynolds stress, turbulent kinetic energy, average concentration and turbulent fluctuation of concentration were measured in a boundary layer wind tunnel in detail. These turbulent properties confirm the effect of buoyancy. In our future work, LES will be used to validate the experimental data. And we plan to investigate more turbulent properties of the thermal buoyant plume of turbulence model from urban fire in detail.

REFERENCES

American Society of Civil Engineering, Wind tunnel studies of buildings and structures, ASCE Manuals and Reports on Engineering Practice No. 67, 1999.

Hayashi, Y., Omiya, Y., Saga T., Ohsaki T. and Wakamatsu, T., Study on flames and thermal plumes induced by fires under windy conditions, Proceeding of 17th National Symposium on Wind Engineering, 173-178. 2002.

Imamura, et al, Proceeding of Japan Association for Fire Science and Technology, 380-383, 2003.

Mell, W. E., McGranttan, K. B. and Baum, H., Numerical simulation of combustion in fire plumes, Twenty-sixth symposium (International) on combustion, 1523-1530, 1996.

Seismic Behavior of ¼ Scale Unreinforced Masonry House Models Retrofitted by PP-band Meshes

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ABSTRACT

This paper introduces a technically feasible and economically affordable PP-band (polypropylene bands) retrofitting for low earthquake resistant masonry structures in developing countries. Results of the basic material tests and shaking table tests on building models show that the PP-band retrofitting technique can enhance safety of both existing and new masonry buildings even in worst case scenario of earthquake ground motion like JMA 7 seismic intensity. Therefore, proposed method can be one of the optimum solutions for promoting safer building construction in developing countries and can contribute earthquake disaster mitigation in the future.

Keywords: unreinforced masonry, polypropylene bands, pp-band mesh retrofitting, shaking table test, arias intensity

1. INTRODUCTION

The collapse of non-engineering masonry is one of the major causes of human casualties during recent earthquakes in developing countries. Therefore, retrofitting of low earthquake-resistant masonry structures is the key issue for earthquake disaster mitigation in developing countries to reduce the casualties significantly. When we propose the retrofitting in developing countries, retrofitting method should respond to the structural demand on strength and/or deformability as well as to availability of material with low cost including manufacturing and delivery, practicability of construction method and durability in each region. Considering these points, PP-band (polypropylene bands, which is worldwide available and cheap material, commonly used for packing) retrofitting technique has been developed and many different aspects have been studied by Meguro Laboratory, Institute of Industrial Science, The University of Tokyo. In order to understand the dynamic response of masonry houses with and without PP-band mesh retrofitting, crack patterns, failure behavior, and overall effectiveness of the retrofitting technique, shaking table tests were carried out. In this experimental program, ¼ scale single box shape room structure with wooden roof models were used. Addition to that, effect of surface plaster on PP-band retrofitted house model also studied.

From the experimental results, it was found that a scaled dwelling model with PP-band mesh retrofitting was able to withstand larger and more repeatable shaking than that without PP band retrofitting, which all verified to reconfirm high earthquake resistant performance. When surface finishing applied above house model, due to improve bond connection between PP-band and brick wall, surface plaster kept well with wall.

2. DESIGN AND CONSTRUCTIONG THE MODELS

2.1 Design of the models

According to the shaking table size and allowable loading condition, the model scaling factor is 1:4 as shown in Figure 1. The model material, we use the unburnt bricks as masonry units and cement, lime and sand (1:2.8:8.5) mixture as mortar with cement/water ratio of 33%, to simulated to the replica of adobe masonry buildings in developing countries.

All the building models dimensions were 933mmx933mmx720mm with 50mm thick walls. The sizes of door and window in opposite walls were 243x485mm^2 and 325x245mm^2 respectively.

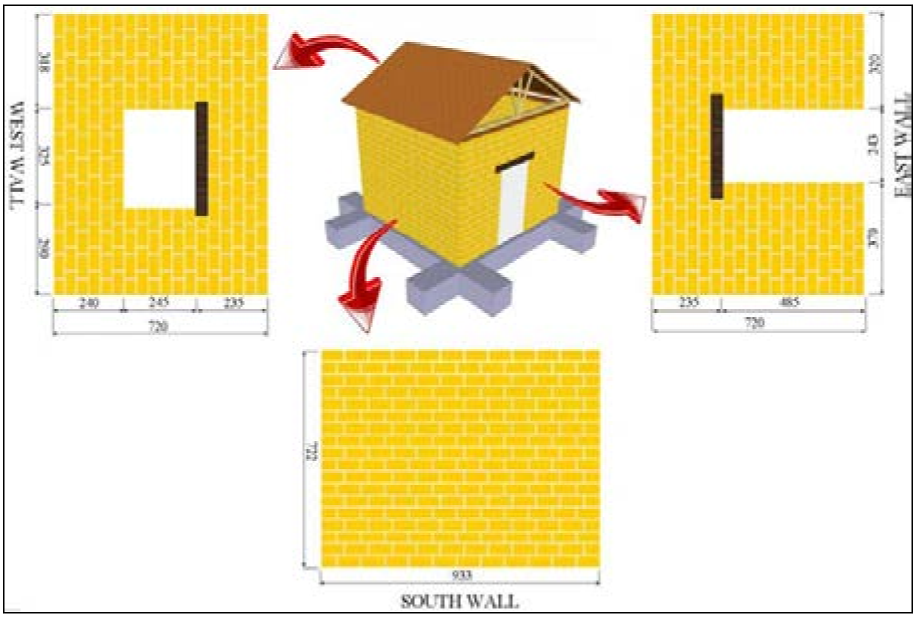


Figure 1: House model for shaking table tests (dimensions in mm)

2.2 Model types

All four models are represented one-storey box-like building with timber roof; two models are non-retrofitted and other two models are retrofitted with PP-band mesh after construction. In each case, one specimen; i.e. one non-retrofitted and one retrofitted, were applied by surface finishing. The mortar thickness covering the inside and outside of walls is 7.5mm. For surface finishing material mixing ratio as follows; Water: Cement: Sand: Lime = 1.00: 0.14: 2.80: 1.11. This simple geometry and boundary conditions were considered as the data generated will be used for numerical modeling in future. Physical characteristic of the models are showed in Table 1.

Table 1: Model types

Model no.	Model name	Brick unit	Roof condition	Retrofitted condition	Surface finishing
1	A-NR-X	Adobe	√		
2	A-RE-X	Adobe	√	√	
3	A-NR-P	Adobe	√		√
4	A-RE-P	Adobe	√	√	√

2.3 Making of Models

All specimens consisted of 18 rows of 44 bricks in each layer except openings. Construction process takes place in two days, first 11 rows in first day and remaining rows construct in following day. The geometry, construction materials and mix proportion, construction process and technique and other conditions that may affect the strength of the building models were kept identical for better comparison. The cross-section of the band used was 6mm×0.32mm and the pitch of the mesh was 40mm. The retrofitted procedure presented in Figure 2 is illustrated with photos taken during the experimental program.

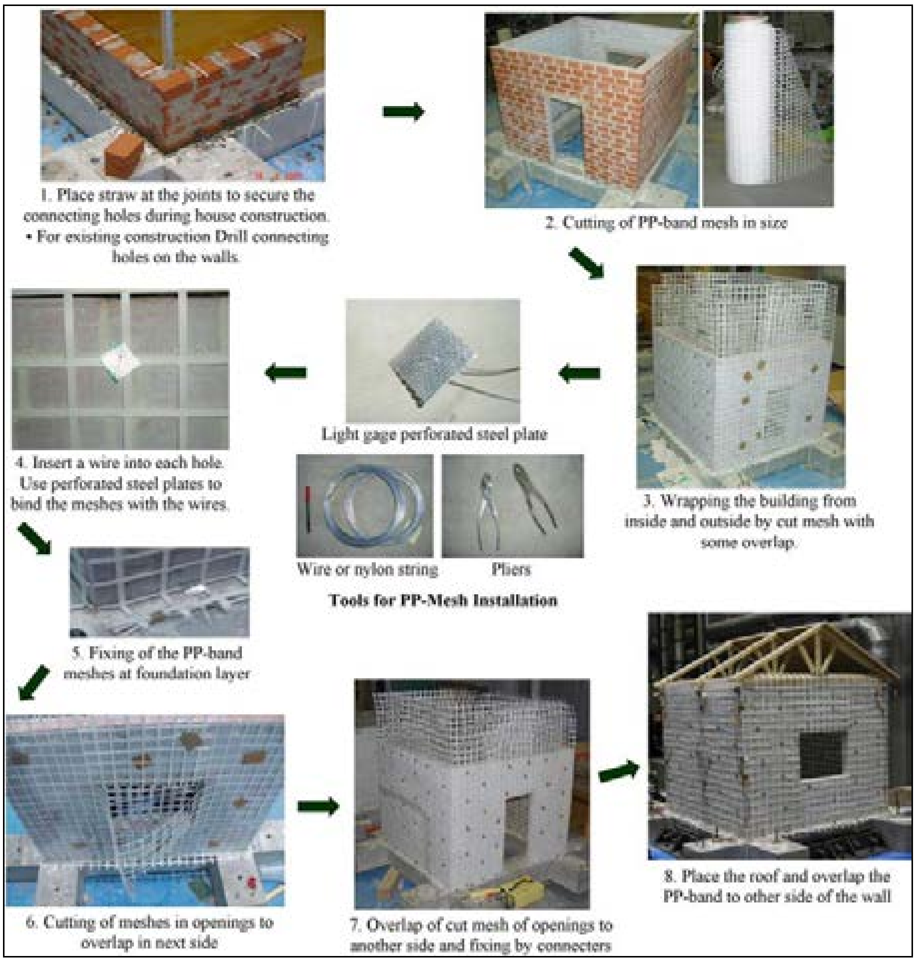


Figure 2: PP-band mesh retrofitting procedure for masonry house

- PP-bands are arranged in meshes and connected at their intersection points using a portable plastic welder.
- Structure walls are cleaned and any loose pieces of brick should be removed.
- Straw, which placed in holes are removed. (In this experiment, during construction of the model house, we put the straw in the place at approximately 160mm pitch where we required holes.) In case of existing structures, holes can be prepared by drilling through the wall.
- Walls are wrapped by meshes around the corners and wall edges. The overlapping length should be long enough to accommodate sufficient wire connectors as this is the only system used to connect meshes to the structure.
- Wires are passed through wall holes and used to connect the meshes on both wall sides. In order to prevent the wires from cutting the PP-band meshes, a plastic piece or any other stiff element is placed between the band and the wire. It is desirable to have connectors as close as possible to the wall intersections and corners.
- The top/bottom mesh edges are connected with steel wires. The bottom edge should be connected to the structure foundation as much as possible. In installing the PP-band mesh on existing houses, it was considered that it would be hard to excavate the ground to bury and fix the mesh bottom to the foundation of the house. The result of treatment only at above ground will save operational cost as well as its workload. Similarly, for existing houses, PP-band mesh attachment on the roof level, the top edges of PP-band mesh need not wrapped the roof.
- Fixed connectors around the openings after the mesh was cut and overlapped on the other side.

3. INPUT MOTION

Simple easy-to-use sinusoidal motions of frequencies ranging from 2Hz to 35 Hz and amplitudes ranging from 0.05g to 1.4g were applied to obtain the dynamic response of both retrofitted and non-retrofitted structures. This simple input motion was applied because of its adequacy for later use in the numerical modeling. Figure 3 shows the typical shape of the applied sinusoidal wave.

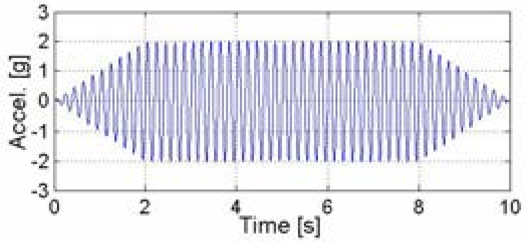


Figure 3: Typical Shape of Input Sinusoidal Motion

Loading was started with a sweep motion of amplitude 0.05g with all frequencies of 2Hz to 35Hz for identifying the dynamic properties of the models.

The numbers in Table 2 indicate the run numbers. General trend of loading was from high frequency to low frequency and from lower amplitude to higher amplitude. Higher frequencies motions were skipped towards the end of the runs.

Table 2: Loading Sequence

Amplitude	Frequency							
	2Hz	5Hz	10Hz	15Hz	20Hz	25Hz	30Hz	35Hz
1.4g		50						
1.2g	54	49						
1.0g		48						
0.8g	53	47	43	40	37	34	31	28
0.6g	52	45	42	39	36	33	30	27
0.4g	51	44	41	38	35	32	29	26
0.2g	46	25	24	23	22	21	20	19
0.1g	18	17	16	15	14	13	12	11
0.05g	10	09	08	07	06	05	04	03
sweep	01,02							

4. ANALYSIS OF THE TEST RESULTS

In order to analyze the test results, the Japan Meteorological Agency intensity and Arias intensity of the input motion as a function of time was calculated.

4.1 Perfomance evaluation based on JMA scale

The Japan Meteorological Agency seismic intensity scale (JMA) is a measure used in Japan to indicate the strength of earthquakes. Unlike the Richter magnitude scale (which measures the total magnitude of the earthquake, and represents the size of the earthquake with a single number) the JMA scale describes the degree of shaking at a point on the Earth's surface.

Table 3: Damage categories

Category	Damage extension
D0: No damage	No damage to structure
D1: Light structural damage	Hair line cracks in very few walls. The structural resistance capacity did not decrease noticeably.
D2: Moderate structural damage	Small cracks were observed on masonry walls. The structure resistance capacity decreased partially.
D3: Heavy structural damage	Large and deep cracks were observed on masonry walls. Some bricks are fallen down. Failure in connection between two walls.
D4: Partially collapse	Serious failure and Partial structural failure was observed on walls and roofs, respectively. The building was in dangerous condition.
D5: Collapse	Structure is totally or partially collapsed.

The performances of the models were assessed based on the damage level of the buildings at different levels of shaking. Performances were evaluated in reference to three levels of performances: light structural damage, moderate structural damage, heavy structural damage, partially collapse and collapse on damage levels described in “European Macroseismic Scale 1998”.

Figure 4 shows the damage evaluation based on JMA intensity for all four models. In case of house models without surface finishing, until Run 26 both models showed the light structural damage levels. From this point, model A-NR-X performed moderate damage level up to Run 40 and after that it's shown rapid degradation and partially collapsed after Run 44. This input motion corresponded to JMA intensity 5-.

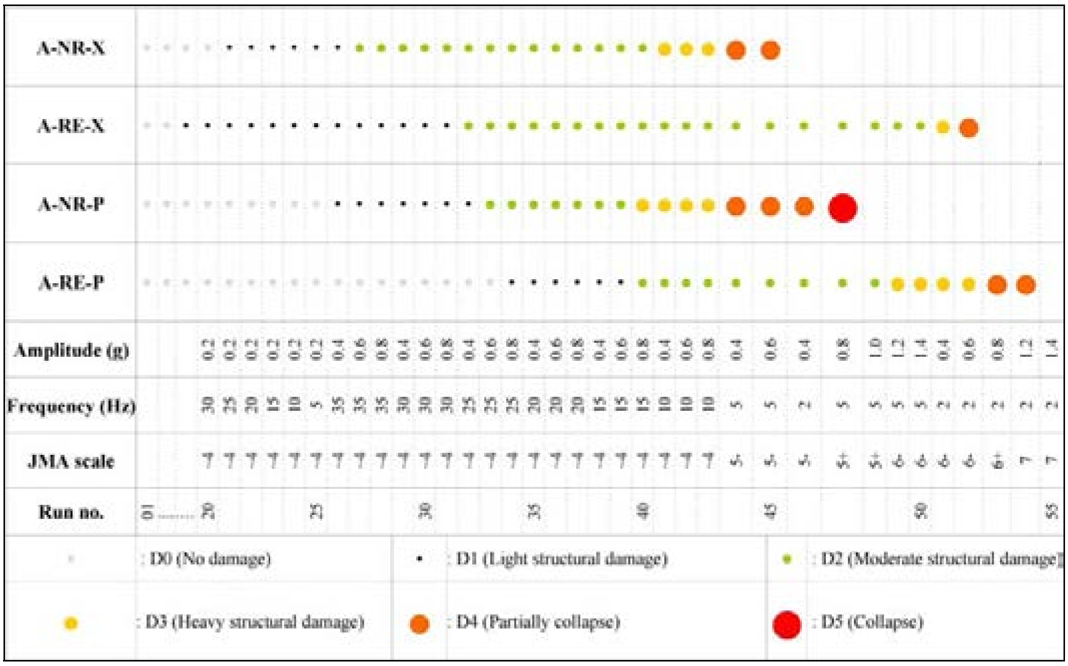


Figure 4: Performance evaluation based on JMA Scale

Model A-RE-X damage, on the other hand, progressed gradually. Although the structure was subjected to four shakes intensity JMAI 6-, it did not collapse. The specimen is cracked, however, no permanent deformations or partial collapse were observed until Run 50. In the field, a structure with this degree of damage can be readily repaired and used. Figure 16(right) depicts A-RE-X after Run 52, which correspond to JMA intensity 6+. It can be seen that even at this stage, the permanent deformations of the structure were limited. Furthermore, escape routes such as doors and windows were secured.

Figure 5: Retrofitted model A-RE-X after Run 50 (left) and Run 52 (right)

In case of house models with surface finishing (A-NR-P & A-RE-P), total collapse of the non-retrofitted building was occurred at the 47th run at intensity JMA 5+. The retrofitted building performed moderate structural damage level at 47th run at which the non-retrofitted building was totally collapsed. Moreover, moderate structural damage level of performance was maintained until 48th run, leading to intensity JMA 5+. It should be noted again that this model survived 7 more shakings in which many runs were with higher intensities than JMA 5+ at which the non-retrofitted building was collapsed before reaching to the final stage at the 54th run.

From this it can be concluded that a structure retrofitted with PP-band meshes would be able to resist strong aftershocks. Moreover, it proves that even though a house retrofitted with PP-band is cracked after a strong earthquake, it can be repaired and be expected to withstand subsequent strong shakes.

4.2 Performance evaluation based on arias intensity

The Arias intensity was initially defined (Arias, 1970) as

$$I_a = \frac{\pi}{2g}\int_0^t a^2(t)dt \tag{1}$$

and was called scalar intensity. It is directly quantifiable through the acceleration record a(t), integrating it over the total duration of the earthquake. The arias intensity is claimed to be measure of the total seismic energy absorbed by the ground. Arias intensity gave cumulative effect of seismic input motion.

Figure 6 and Figure 7 show the performance level of each specimen against the dynamic motion. Form results, it clearly showed that; retrofitted model damage level performance at least 3 times better than that of the non-retrofitted model.

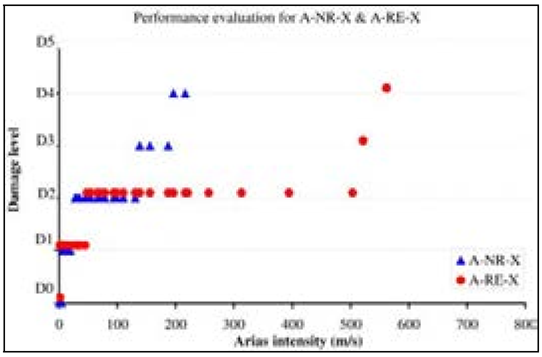


Figure 6: Performance evaluation for models A-NR-X & A-RE-X

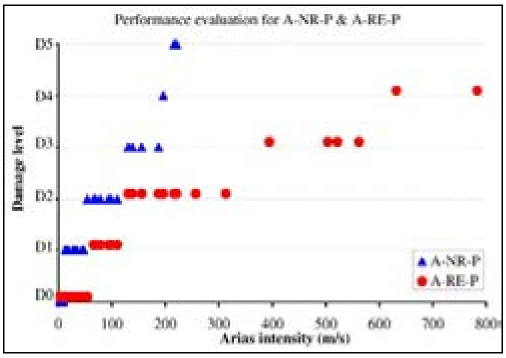


Figure 7: Performance evaluation for models A-NR-P & A-RE-P

4.3 Lateral drift

In design, drift (i.e. story drift/story height) limits can be used to control the extent of structural and nonstructural damage in the building. Hence, the drift levels that correspond to the onset of a major damage in the teat models were summarized in Table 4. These can be used as approximate guidelines for design.

As we can be observed from Table 4, in all the models tested, the moderate structural damage occurred at a drift between 0.14mm and 0.20mm, except A-RE-P. For both non retrofitted models very heavy structural damage/partially collapse occurred at a drift around 3mm. However, in case of retrofitted models, it went up to 29mm and 50mm for A-RE-X and A-RE-P, respectively. It indicates the retrofitted house could withstand at least lateral drift level 10 times larger than the non-retrofitted house, even without any surface finishing applied.

Table 4: Drift levels in mm at various damage levels

Model name.	Damage level		
	Light Structural damage	Moderate structural damage	Heavy structural damage
A-NR-X	~ 0.14	0.14-1.47	1.47-3.39
A-RE-X	~0.20	0.20-7.00	7.00-28.90
A-NR-P	~0.17	0.17-0.61	0.61-2.62
A-RE-P	~0.96	0.96-17.86	17.86-49.93

Considering the predominant first vibration mode shape of vibration, and assuming that the observed mode shape is stable during the shaking, and neglecting the damping, base shear and story lateral force can be determined. Lateral shear force is determined as a sum of inertia forces acting on walls:

$$SS = \sum_{1}^{n} m_i a_i \tag{2}$$

Where SS is the lateral shear force, mi pertinent mass at each location, ai the acceleration and n the number of location considers for calculation. Figure 8 and Figure 9 shows the lateral shear force variation with lateral drift for models without surface finishing and models with surface finishing, respectively. In both cases, before major cracking observed in specimens; different in lateral shear force between non-retrofitted and retrofitted models was not observed.

However, after cracking, both retrofitted specimens were shown the higher story lateral force; even lateral drift more than 20mm. It indicates after cracking, the mesh presence positively influenced the lateral resistance of the specimen.

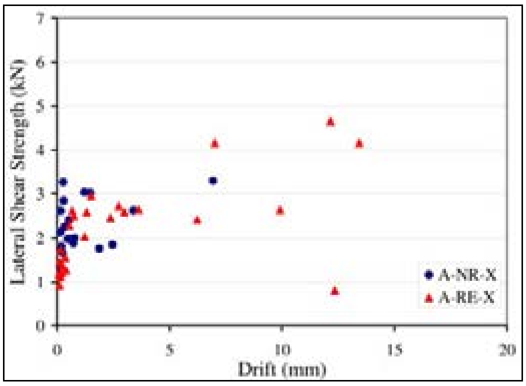


Figure 8: comparison of lateral shear force between A-NR-X and A-RE-X

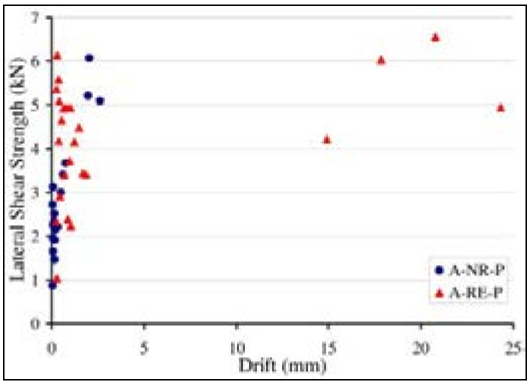


Figure 9: Comparison of lateral shear force between A-NR-X and A-RE-X

4.4 Stiffness degradation

Masonry is an inelastic structural material, which doesn't behave elastically even in the range of small deformation. However, for a practical reason, effective stiffness of the wall, defining the slope of the hysteresis curves, is determined as the ratio between lateral force and deformation in the house model. Calculated values after each run are shown in Figure 10.

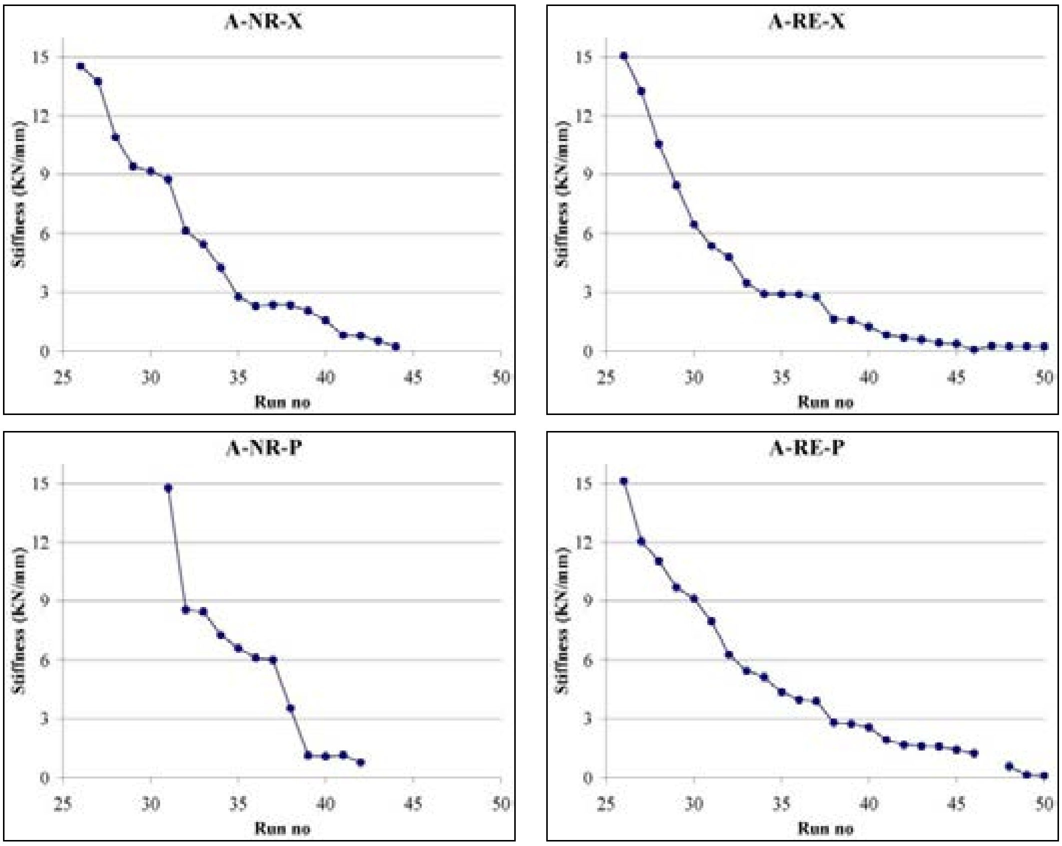
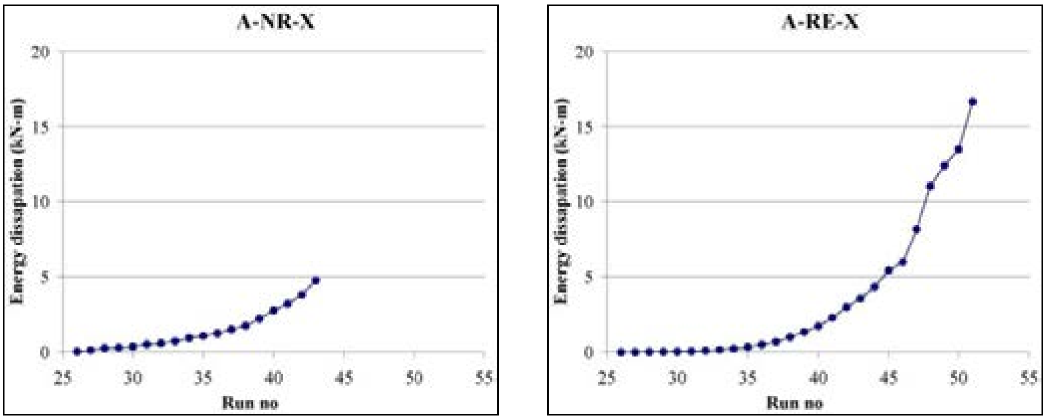


Figure 10: Stiffness degradation for each house models



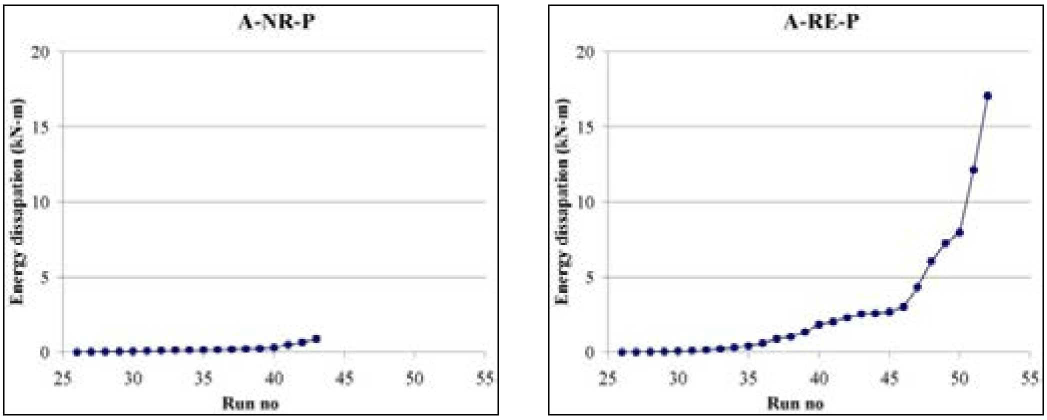


Figure 11: Energy dissipation for each house models

4.5 Energy dissipation

The comparison among the values of energies related to different severities of the base excitation is meaningful. However, in some instances it is useful to normalize cumulated energy time histories with respect to the impedance of the excitation. The energy dissipated in each cycle is the area enclosed by the hysteresis loop corresponding to that cycle. The energy dissipated by whole house model corresponds to total house model force and the horizontal displacement of the top of the house model.

To assess the overall performance of the structures, energy dissipation in terms of input runs is shown in Figure 11. Generally, energy dissipation capacity of the retrofitted house specimen was much larger than non-retrofitted house specimens.

5. CONCLUSIONS

The shaking table experiments showed that; scaled dwelling model with PP-band mesh retrofitting can withstand larger and more repeatable shaking than that without PP band retrofitting. Which all verified to reconfirm that, the PP-band retrofitting technique significantly enhanced the structural seismic performance. When we applied the surface finishing to above house model, due to improve bond connection between PP-band and brick wall, surface plaster kept well with wall. This is not observed in the non-retrofitted model. Addition to this, covering the mesh with mortar is very important to fill up any gaps between mesh and masonry thus improving the structural performance. The mortar also protects the mesh against UV radiation and sharp temperature variations as well as provides a smooth finishing to the retrofitted structure.

From all the experimental results, it was found that this retrofitting technique can enhance safety of both existing and new masonry buildings even in worst case scenario of earthquake ground motion like JMA 7 intensity. Therefore, PP-band retrofitting method can be one of the optimum solutions for promoting safer building construction in developing countries and can contribute earthquake disaster in the future.

REFERENCES

Yoshimura, M. and Meguro, K., 2004. Proposal of Retrofitting Promotion System for Low Earthquake-Resistant Structures in Earthquake Prone Countries, *Proc. of the 13th World Conference on Earthquake Engineering*, Vancouver, Canada.

Meguro, K., Mayorca, P., Sathiparan, N., Guragain, R., and Nesheli, N., 2005. Shaking Table Tests of 1/4 Scaled Masonry Models Retrofitted with PP-band Meshes, *Proc. of the Third International Symposium on New Technologies for Urban Safety of Mega Cities in Asia*, Singapore, pp. 9-18.

European Macroseismic Scale 1998 (EMS-98), 1998. Grunthal, G. (ed.), *European Seismological Commission*, GeoForschungsZentrum Potsdam, Germany.

Coburn, A. and Spence, R., 2002. *Earthquake Protection*. John Wiley & Sons Ltd, West Sussex.

Travasarou, Thaleia., Bray, J.D., and Abrahamson, N.A., 2003, Empirical attenuation relationship for Arias Intensity, *Earthquake engineering & structural dynamics*, vol. 32, pp 1133-1155.

Assessment of fire loss in building based on fire statistic data

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ABSTRACT

In this paper, taking the fire occurrence reasons as the classification criteria for the building fire statistics data, a detailed analysis and evaluation was conducted to obtain the correlation between the causes of the fire and the building fire loss.
The analysis results using the Gray Correlation Analysis to the sub-loss statistics data showed that the fire numbers and fire loss caused by the electric, illegal operation, careless use of fire, smoking and spontaneous combustion reasons are the mainly factors which influence the overall fire numbers and the fire loss in China. These kinds of fire causes should be treated as the focus of fire prevention. Persons' unsafe behavior such as illegal operation, careless use of fire, smoking, as well as the combustible which may cause the spontaneous combustion being in unsafe conditions should be paid great attention to.
Based on the statistical data of the fire cases, probability analysis was used to study the fire frequency distribution, loss expectation, the maximal risk sub-loss, fire frequency and loss expectation of the maximal risk sub-loss aroused by various fire causes. The results showed that under the current social and economical development conditions in China, the occurrence of electrical fire and the above 100,000 fire sub-loss had the greatest risk.
Through the analysis, the focus and the weak point can be found out, which will support the adjustment for fire safety regulations and measures, to find the main disaster-reducing direction, and to carry out the fire prevention work with more pertinency.

Keywords: fire loss, fire cause, fire statistics, Gray Correlation Analysis

1. INTRODUCTION

As a kind of disaster, the occurrence and the development of fire appears both randomicity and certainty. A single fire will not show any probabilistic law, yet large numbers of fires arises during a period of time often present some obvious probatilistic rules, which is the theoretical basis of fire statistics. Through the fire statistics analysis, the fire hazard rating of a region can be summarized, furthermore a more detailed analysis and evaluation will support the adjustment for fire safety regulations and measures, to find the main disaster-reducing direction, and to carry out the fire prevention work with more pertinency. The fire statistics is one of the important basis for the fire department to understand the fire development laws, to judge the fire situation, to establish the fire prevention plan, to make the fire emergency response plan, etc. (Liu, et al.,2005). In China, the fire statistics mainly aims at the direct property loss caused by the building fires, which included the fire loss caused by burning, smudging, radiation, collision during the fire and the extinguishment, waterlogging, the pollutions caused by the fire, etc. (Ministry of Public Security of PRC, 1999).

Many researches on the fire statistic methods have been done, various of fire statistic and evaluation models were advanced. Most of the models are based on the fire mechanism researches, using the computer numerical simulation technology, statistical probability theory, fuzzy mathematical theory to evaluate the fire loss. Li, et al.(1997) educed the calculation formula of the building fire safety levels, via comparing the fire risk factors and the building safety factors. Wang, et al.(2002) established a neural network model to predict the annual fire loss in China in 1994, using the 1971-1993 annual fire loss statistic data. Chu, et al.(2004) established a evaluation method for the direct fire property loss based on the prediction of fire-burned area using event tree analysis method and statistical probability theory. Jiang, et al.(2005) drew a conclusion that the fire loss in China present a ascending trend and predicted the intending annual fire loss in the following years, which was acquired using the time-trend analysis based on the fire statistic data of China. Chen, et al.(2007) estimated the regional fire loss in China using the cluster analysis, and the relationship between the regional economic level, the fire prevention investment and the fire loss were discussed.

Fire loss were considered as a kind of disaster loss in the above-mentioned researches, the main purpose is to predict the future fire loss using the statistic significance. In this paper, the main purpose is to study the influence of the fire caused to the fire numbers and fire loss using the Gray Correlation Analysis based on the 1999-2007 fire statistic data, main factors which influence the overall fire numbers and the fire loss in China are found out through the analysis. The results will support the adjustment for fire safety regulations and measures, to find the main disaster-reducing direction, and to carry out the fire prevention work with more pertinency.

2. FIRE SUB-LOSS

Based on the fire statistic data, the fire loss can be divided into five sub-loss level: 0-1,000, 1,000-10,000, 10,000-50,000, 50,000-100,000, above 100,000. Using the sub-loss, the 1999-2007 statistic data of fire numbers and fire loss are showed in Table 1.

Table 1: 1999-2007 fire number and fire loss of sub-loss

Sub-loss	**Fire numbers**	**Rates of fire numbers**	**Fire loss**	**Average loss**	**Rates of fire loss**
0-1,000	20,764	0.6365	6,757,123	325.42	0.0396
1,000-10,000	9,145	0.2803	25,537,299	2,792.49	0.1495
10,000-50,000	2,011	0.0616	41,156,115	20,465.50	0.2409

50,000-100,000	379	0.0116	25,040,892	66,070.96	0.1466
Above 100,000	324	0.0100	72,351,095	223,305.85	0.4234
SUM	32,623	1	170,842,524	-	1

1) The majority of fire loss caused by a single fire lies in the 0-1,000 sub-loss, the percentage is 63.6%, however, the total fire loss of these fires is less than 4% of all fire loss; 28% of the fire loss caused by a sing fire lies in the 1,000-10,000 sub-loss, yet the total fire loss of these fires is less than 15% of all fire loss. This result shows that most of the fire can be put out effectively at the initial stage, and the fire loss can be controlled at a relatively low level.

2) Nearly 6.2% of the fire loss caused by a sing fire lies in the 10,000-50,000 sub-loss, whereas the total fire loss of these fires is more than 24% of all fire loss; less than 1.2% of the fire loss the fire loss caused by a sing fire lies in the 50,000-100,000 sub-loss, while the total fire loss of these fires is more than 14% of all fire loss. The result shows that the fire whose loss lies in the 10,000-100,000 sub-loss, especially the 10,000-50,000 sub-loss is the important target of the fire prevention t job which should be given significant attention.

3) A very few of fire loss caused by a single fire lies in the above 100,000 sub-loss, the percentage is only 1%, however, the total fire loss of these fires is more than 42% of all fire loss. This result shows that the fires whose fire loss lies in the above 100,000 sub-loss is the most important factor which influence the high fire loss in China, this kind of fire is also the chief target of the fire prevention job.

3. FIRE CAUSES GRAY CORRELATION ANALYSIS OF SUB-LOSS

The occurrence of fire is a random process, the fire causes can be divided into ten categories of reasons in China (Fire Department of Ministry of Public Security of PRC, 1999): incendiarism, electric, illegal operation, careless use of fire, smoking, fire play, spontaneous combustion, lightning stroke, unknown and others. The fire numbers and fire loss of different kinds of reasons are different, Gray Correlation Analysis is used to analysis the fire statistic data of every sub-loss, the influence degree of different fire causes to fire numbers and fire loss is derived.

3.1 Gray Correlation Analysis theory

The relational degree is used to analyze the fire statistic data, the absolute relational degree is calculated out using the nearness degree of the changing trend of the influence factors' time series. As for the discrete data series, the nearness degree of two curves is determined by the nearness of the gradient of the time series curves at the corresponding time interval, the less of the differentials of the curves' gradient, the more relational degree of the two factors is, vice versa. The absolute relational degree can be calculated as follows:

The original data series is:

$$X = \{x_i = (x_i(1),\ x_i(2), \cdots,\ x_i(n)),\ i = 0,1, \cdots,\ m\}$$

Suppose,

$$y_i(k) = x_i(k)/x_i(1),\ i = 0,1, \cdots,\ m$$
$$\Delta y_{0i}(k) = y_0(k) - y_i(k),\ i = 0,1, \cdots,\ m$$
$$\Delta y_i(k) = y_i(k) - y_i(k-1),\ i = 0,1, \cdots,\ m$$

then the calculation formula of the absolute relational degree is (equation 1):

$$r_{0i} = \frac{1}{n-1}\sum_{k=2}^{n}\frac{1}{1+|\Delta y_{0i}(k) - \Delta y_i(k)|} \quad (1)$$

3.2 Gray Correlation Analysis of fire causes and fire numbers

Using Gray Correlation Analysis method to analysis the fire numbers and the fire causes statistic data lies in 0-1,000 sub-loss, Table 2 is obtained as follows.

Table 2: fire causes and fire numbers lies in 0-1,000 sub-loss

Year	**Total**	**Fire causes**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1999	850	27	228	64	165	29	63	4	2	184	84
2000	1228	41	460	72	291	56	61	14	4	158	71
2001	1336	35	575	88	357	46	50	27	1	84	73
2002	744	29	293	58	188	44	46	7	2	51	26
2003	705	32	273	71	161	37	31	9	0	50	41
2004	540	20	183	43	155	40	30	9	1	47	12
2005	615	27	231	33	168	26	21	15	1	58	35
2006	6603	173	2905	224	1404	426	291	93	7	566	514
2007	8143	124	3355	230	1676	744	527	145	16	360	966

1.Incendiarism, 2.Electric, 3.Illegal operation, 4.Careless use of fire, 5.Smoking, 6.Fire play, 7.Spontaneous combustion, 8.Lightning stroke, 9.Unknown, 10.Others

And the correlation degree of fire causes and fire numbers obtained from the fire statistic data lies in 0-1,000 sub-loss is listed in Table 3.

Table 3: Correlation of fire causes and fire numbers of 0-1,000 sub-loss

Fire causes	**Correlation degree**
Incendiarism	0.51146
Electric	0.758133
Illegal operation	0.511856
Careless use of fire	0.622782
Smoking	0.543832
Fire play	0.516978
Spontaneous combustion	0.51146
Lightning stroke	0.500502
Unknown	0.500026
Others	0.533032

Table 3 shows that the influence sequence of fire causes to the fire numbers, from high to low, is electric, careless use of fire, smoking, others, fire play, illegal operation, incendiarism, spontaneous combustion, lightning stroke, unknown.

The same analysis is conducted to the fire statistic data lies in the 1,000-10,000, 10,000-50,000, 50,000-100,000, and above 100,000 sub-loss. The influence sequence of fire causes to the fire numbers of different sub-loss differs, too, as follows:

1,000-10,000 sub-loss, from high to low: electric, careless use of fire, spontaneous combustion, illegal operation, smoking, incendiarism, fire play, unknown, lightning stroke, others.
10,000-50,000 sub-loss, from high to low: electric, unknown, illegal operation, others, fire play, incendiarism, careless use of fire, smoking, lightning stroke, spontaneous combustion.
50,000-100,000 sub-loss, from high to low: electric, illegal operation, careless use of fire, smoking, incendiarism, unknown, fire play, lightning stroke, spontaneous combustion, others.
Above 100,000 sub-loss, from high to low: illegal operation, smoking, incendiarism, unknown, careless use of fire, fire play, lightning stroke, electric, others, spontaneous combustion.

3.3 Gray Correlation Analysis of fire causes and fire loss

Using Gray Correlation Analysis method to analysis the fire loss and the fire causes statistic data lies in 0-1,000 sub-loss, Table 4 is obtained as follows.

Table 4: fire causes and fire loss of 0-1000 sub-loss

Year	**Total**	**Fire causes**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1999	29.4655	0.8267	8.2397	2.3010	5.7535	0.9680	2.4050	0.1200	0.9000	5.8066	2.9550
2000	44.5906	1.5770	16.8677	2.6600	10.1720	2.1695	2.4670	0.6100	0.1762	5.3472	2.5440
2001	38.6898	1.1369	16.5725	2.6595	10.0092	1.3561	1.6144	0.6735	0.0500	2.4462	2.1715
2002	24.2647	0.7406	1.3081	1.7238	5.8567	1.4100	1.6110	0.2710	0.0350	1.4450	0.8635
2003	25.4904	0.9520	10.0438	2.2308	5.9980	1.3250	1.1700	0.3600	0	1.9003	1.5105
2004	21.4780	0.7246	7.5147	1.8631	6.1615	1.2530	1.2200	0.4200	0.0500	1.9130	0.3581
2005	26.1337	0.9875	10.3318	1.1958	7.6654	0.9110	0.6735	0.5482	0.0700	2.2700	1.4805
2006	198.7504	5.1031	92.9962	7.5502	44.0567	10.8116	7.6932	2.4654	0.2500	15.3258	12.4982
2007	266.8492	4.1546	118.4587	8.0806	55.3694	23.1867	15.3865	5.4650	0.5010	9.0523	27.1944

1.Incendiarism, 2.Electric, 3.Illegal operation, 4.Careless use of fire, 5.Smoking, 6.Fire play, 7.Spontaneous combustion, 8.Lightning stroke, 9.Unknown, 10.Others

And the correlation degree of fire causes and fire loss obtained from the fire statistic data lies in 0-1,000 sub-loss is listed in Table 5.

Table 5: Correlation of fire causes and fire loss of 0-1,000 sub-loss

Fire causes	**Correlation degree**
Incendiarism	0.512997
Electric	0.778052
Illegal operation	0.512257

Careless use of fire	0.628199
Smoking	0.541168
Fire play	0.511297
Spontaneous combustion	0.513137
Lightning stroke	0.501209
Unknown	0.500831
Others	0.522853

Table 5 shows that the influence sequence of fire causes to the fire numbers, from high to low, is electric, careless use of fire, smoking, others, spontaneous combustion, incendiarism, illegal operation, fire play, lightning stroke, unknown.

The same analysis is conducted to the fire statistic data lies in the 1,000-10,000, 10,000-50,000, 50,000-100,000, and above 100,000 sub-loss. The influence sequence of fire causes to the fire numbers of different sub-loss differs, too, as follows:

1,000-10,000 sub-loss, from high to low: electric, careless use of fire, spontaneous combustion, smoking, unknown, incendiarism, fire play, lightning stroke, illegal operation, others.
10,000-50,000 sub-loss, from high to low: unknown, electric, illegal operation, others, careless use of fire, fire play, incendiarism, smoking, lightning stroke, spontaneous combustion.
50,000-100,000 sub-loss, from high to low: electric, illegal operation, careless use of fire, smoking, incendiarism, unknown, fire play, lightning stroke, spontaneous combustion, others.
Above 100,000 sub-loss, from high to low: spontaneous combustion, electric, lightning stroke, unknown, fire play, incendiarism, others, smoking, careless use of fire, illegal operation.

3.4 Conclusion of the Gray Correlation Analysis of sub-loss

The analysis results using the Gray Correlation Analysis to the sub-loss statistics data showed that the fire numbers and fire loss caused by the electric, illegal operation, careless use of fire, smoking and spontaneous combustion reasons are the mainly factors which influence the overall fire numbers and the fire loss under the current social and economical development conditions in China. These kinds of fire causes should be treated as the focus of fire prevention. Persons' unsafe behavior such as illegal operation, careless use of fire, smoking, as well as the combustible which may cause the spontaneous combustion being in unsafe conditions should be paid great attention to.

4. PROBABILITY ANALYSIS OF SUB-LOSS

Based on the statistical data of the fire cases, probability analysis is used to study the fire frequency distribution, loss expectation, the maximal risk sub-loss, fire frequency and loss expectation of the maximal risk sub-loss aroused by various fire causes.

4.1 Fire risk

The basic formula of fire risk can be expressed as follows (equation 2):

$$R = \sum_i (Pi \times Ci) \tag{2}$$

Pi is the probability of occurrence of a single fire event, *Ci* is the anticipated consequence of this fire event. In this paper, the *Pi* is replaced by the occurrence frequency of fire, and *Ci* is replaced by the average loss.

4.2 Risk analysis of sub-loss and fire causes

The fire occurrence frequency, the average loss and the fire risk of different sub-loss is calculated out, as listed in Table 6.

Table 6: Risk analysis of sub-loss

Sub-loss	Fire numbers	Frequency	Fire loss	Average loss	Fire risk
0-1,000	20,764	0.6365	6,757,123	325.42	207.13
1,000-10,000	9,145	0.2803	25,537,299	2,792.49	782.80
10,000-50,000	2,011	0.0616	41,156,115	20,465.50	1261.57
50,000-100,000	379	0.0116	25,040,892	66,070.96	767.58
Above 100,000	324	0.0100	72,351,095	223,305.85	2233.06
SUM	32,623	1	170,842,524	-	-

Table 6 shows that the fire risk of different sub-loss, from high to low, is above 100,000 sub-loss, 10,000-50,000 sub-loss, 1,000-10,000 sub-loss, 50,000-100,000 sub-loss, 0-1,000 sub-loss.

The fire occurrence frequency, the average loss and the fire risk of different fire caused is calculated out, as listed in Table 7.

Table 7: Risk analysis of sub-loss

Fire cause	Fire numbers	Frequency	Fire loss	Average loss	Fire risk
Incendiarism	1156	0.0354	12010234	10389.48	368.15
Electric	13737	0.4211	66609496	4848.91	2041.80
Illegal operation	1838	0.0563	21689008	11800.33	664.84
Careless use of fire	6544	0.2006	17421325	2662.18	534.02
Smoking	1857	0.0569	3758178	2023.79	115.20
Fire play	1542	0.0473	4987632	3234.52	152.89
Spontaneous combustion	685	0.0210	5709546	8335.10	175.02
Lightning stroke	80	0.0025	2776492	34706.15	85.11
Unknown	2634	0.0807	21982926	8345.83	673.85
Others	2550	0.0782	13897687	5450.07	426.01
SUM	32623	1	170842524	-	-

Table 7 shows that the fire risk of different fire causes, from high to low, is electric, unknown, illegal operation, careless use of fire, others, incendiarism, spontaneous combustion, fire play, smoking, lightning stroke.

The results showed that under the current social and economical development conditions in China, the occurrence of electrical fire and the above 100,000 fire sub-loss had the greatest risk.

5. CONCLUSION

Taking the fire occurrence reasons as the classification criteria for the building fire statistics data, a detailed analysis and evaluation was conducted to obtain the correlation between the causes of the fire and the building fire loss. Through the analysis, the focus and the weak point is found out, which will support the adjustment for fire safety regulations and measures, to find the main disaster-reducing direction, and to carry out the fire prevention work with more pertinency.

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REFERENCES

Liu, D. H., Ji, T., Gao, J. T., Bai, F. L., 2005. Discussions on the fire statistics. *Fire Technique and Products Information* 2, 35-37.
Ministry of Public Security of PRC, 1999. *GA185-1998 Statistic method for the fire direct property loss*. Standards Press of China, Beijing.
Yang, L. Z., Zhou, X. D., Deng, Z. H., Fan, W. C., Wang, Q. A., 2002. Fire situation and fire characteristic analysis based on fire statistics of China. *Fire Safety Journal* 37(8), 785-802.
Li, Y. Q., Ji, G. Q., Li, S. H., Liang, S. M., Deng, Z. X., 1997. The research of statistical fire loss calculated method. *Fire Safety Science* 6(2), 24-32.
Wang, C., Li, C., 2002. Application of BP network in fire forecasting. *Journal of the Chinese People's Armed Police Force Academy* 18(2), 25-27.
Chu, G. Q., Sun, J. H., 2004. Building fire direct loss evaluation based on fire dynamics and probability statistics theory. *Engineering Science* 6(8), 64-68.
Jiang, X. P., Xu, Z. S., 2005. Analysis and prediction on the time trend of fire cost in China. *Fire Science and Technology* 24(4), 412-414.
Chen, Z. J., Wang, F. L., Lu, S. X., Fang, Z. B., 2007. Cluster analysis of fire data in china. *Engineering Science* 9(1), 86-94.
Fire Department of Ministry of Public Security of PRC, 1999. *Fire accident investigation*. Jilin Science and Technology Press, Changchun.
Liu, S. F., Dang, Y. G., Fang, Z. G., Xie, N. M., 2004. *Gray system theory and application*. Science Press, Beijing.

PEOPLE'S SEISMIC RISK RECOGNITION IN DHAKA AND BANGLADESH NATIONAL BUILDING CODE (BNBC) 1993

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ABSTRACT

Dhaka, the fastest growing megacity in Asia, is prone to natural disasters including earthquake. The present generation have never witnessed big earthquake since the last one in 1897 that destroyed 60% masonry structures with mass casualty. According to shaking intensity data, the same earthquake may recur at any time, which requires good level of knowledge and earthquake resistant infrastructure to mitigate loss. However, rapid urbanization of Dhaka did not concentrate much on earthquake risk; buildings are constructed in an unregulated manner without earthquake consideration, which questions people's risk recognition. In order to examine inhabitant's risk recognition and intention for residential safety measures, the authors conducted questionnaire survey in eighteen selected wards of Dhaka. The questionnaire content house construction year, type, disaster experience, recognition of emergency, anticipated large disaster, risk recognition, acceptable risk, safety measures, cause of destroyed house, willingness to pay, and knowledge on Bangladesh National Building Code (BNBC). Based on the obtained data, major result shows that inhabitants anticipate earthquake as the most catastrophic disaster for Dhaka, which may occur in 5-10 years; and cost cut, lack of information, and not following proper design will be the main cause of destroyed houses. Result shows only 2.4% respondent heard about the BNBC, but they do not know the contents. Then the authors checked the present status of BNBC with construction practice and conducted interview with BRAC University, Bangladesh University of Science and Technology (BUET), Rajdhani Unnayan Kartipakkha (RAJUK), and Housing and Building Research Institute (HBRI). In conclusion, the paper shows– (1) inhabitants construct buildings without following approved design, (2) BNBC is not followed in constructing new buildings, (3) BNBC is included under law, but no building legally follow it, (4) a big number of buildings, constructed before and after 1993, may perform poorly in big earthquake.

1. INTRODUCTION

Dhaka is considered the fastest growing megacity in Asia for its rapid urbanization, population growth and incensing geographic area. Due to the concentration of both domestic and foreign investment, Dhaka has experienced massive migration from the rural population in recent decades (Hossain 2008). The city is prone to natural disaster including earthquake. The present generation never have witnessed large earthquake since the last one in 1897 that destroyed about 60% of masonry structures with much casualty (Al-Hussaini 2003). Bilham and England (2001) cited that this earthquake would recur and affect Dhaka at anytime, which requires good level of knowledge and earthquake resistant infrastructure to mitigate loss. However, the city did not concentrate much on earthquake risk. Buildings are constructed in an unregulated manner without earthquake consideration, which questions people's risk recognition. In order to examine inhabitant's risk recognition and intention for residential safety measures, the authors conducted a questionnaire survey in eighteen selected wards of Dhaka. The objective of the paper is to clarify the survey outcomes, which might be useful for adopting residential safety measures in Dhaka city.

2. METHODOLOGY

This study applied literature review, questionnaire survey and interview methods to achieve the objective. The steps are explained below.

2.1 Literature review:

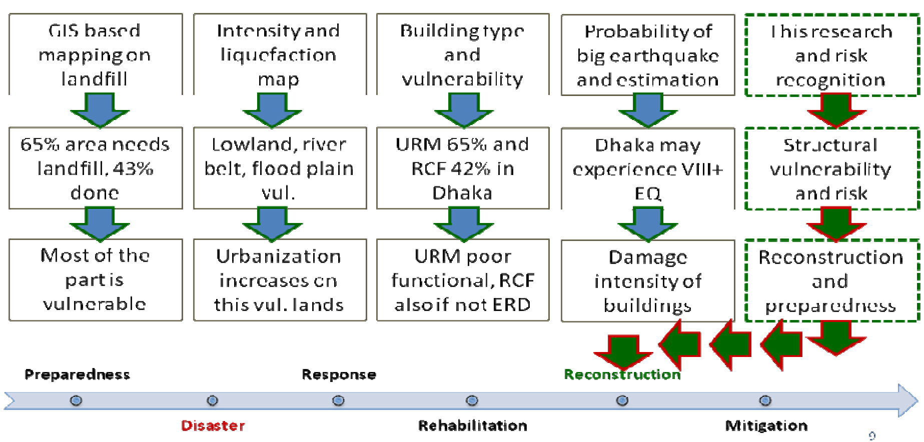


Figure-1: Analysis of reviewed literatures and status of this study

Figure-1 shows the reviewed literature flow. Total four types of literatures were identified and collected on Dhaka's earthquake vulnerability (Kamal 2004, Ansary 2000, Al-Hussaini 2003, Ansary 2004), which have been shown in the first four columns of first row in Figure-1. The second row shows the major findings of those literatures and the third row shows the results. The fifth column of the figure and consequent rows explains the scope of this study, probable findings and expected results. The authors found that present study is new in its type and no previous research focused on people's risk recognition. This study will contribute to reconstruction phase of typical disaster management cycle, which has been shown at the bottom of the figure.

2.2 Cluster analysis of wards:

The authors collected Dhaka's ninety wards' characteristics data from Dhaka City Corporation (DCC), Bangladesh Bureau of Statistics (BSS) and Bangladesh University of Engineering and Technology (BUET). This included population, density, building number and density, number of block, open space and earthquake intensity (done by BUET). Three variables of population density, building density, and probable earthquake intensity were selected for cluster analysis in statistical software STATA and result was derived in three clusters like less vulnerable, most vulnerable, and moderate vulnerable. Taking six wards from each cluster, total eighteen wards were selected for the questionnaire survey.

2.3 Contents of the questionnaire:

The questionnaire mainly contained the house construction year, type, major structure, disaster experience, recognition of emergency, anticipated large disaster, risk recognition, acceptable risk, safety measures, cause of destroyed house, willingness to pay, and knowledge on Bangladesh National Building Code (BNBC). Total 720 sample were collected i.e. 40 from each ward. The next chapter shows the major results of the questionnaire survey based on the obtained data.

3. MAJOR RESULTS

3.1 Basic information of the respondents:

First, we analyze the basic information of the respondents and their residence, which we explain in following figures.

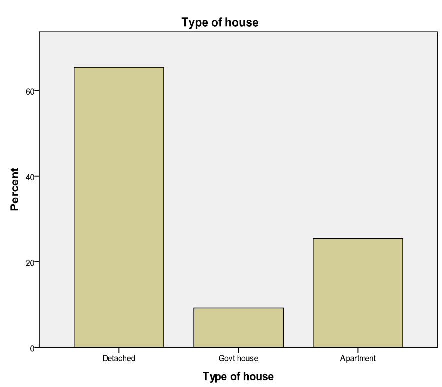


Figure-2: Type of buildings

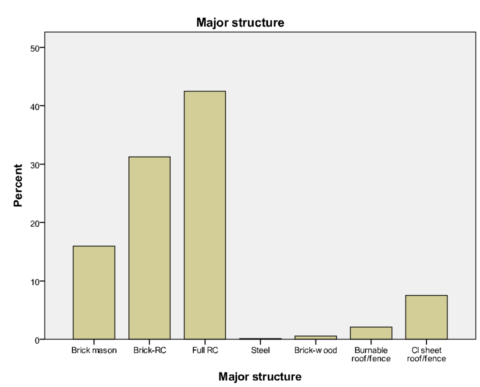


Figure-3: Major structure of buildings

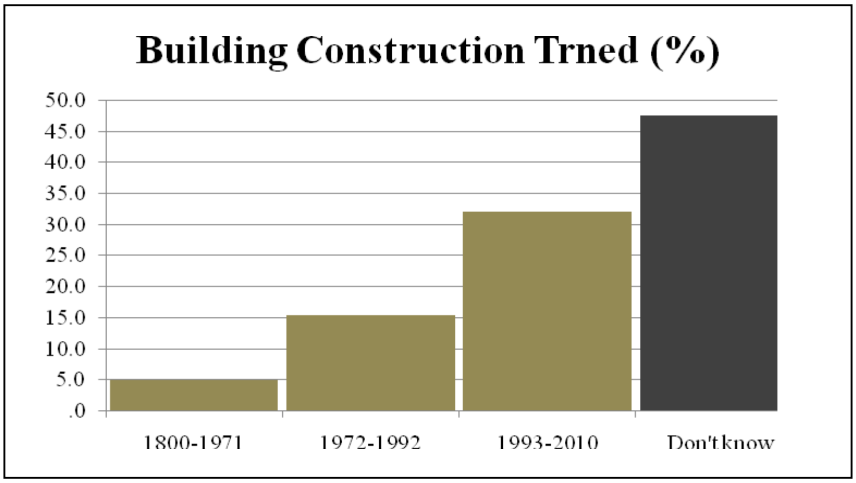


Figure-4: Building construction trend in percentage

Figure-2 shows three types of residential buildings in Dhaka. They are detached houses (65.4%), government houses (9.2%) and apartment houses (25.4%). Figure-3 shows the major structure of buildings. About 42.5% are full RC structure, 31.3% are brick and RC, and 16% are masonry structure. Most of the buildings in Dhaka are RC structure, which are stronger than wooden houses. However, as shown in Figure-14, they are vulnerable as they do not followed building code properly. Figure-4 demonstrated the building construction trend. We observed a rising tendency in building construction. From 1800 to 1971, buildings were increasing in a long interval. From 1972 to 1992, it became upward. And from 1993 to 2010, the tendency became liner and straight upward.

3.2 Disaster experience and recognition of emergency:

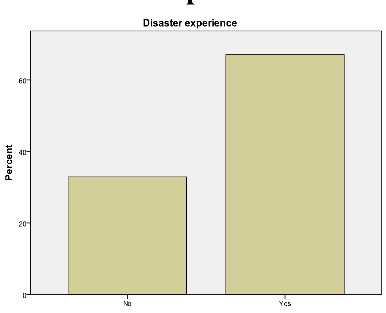


Figure-5: Disaster experience

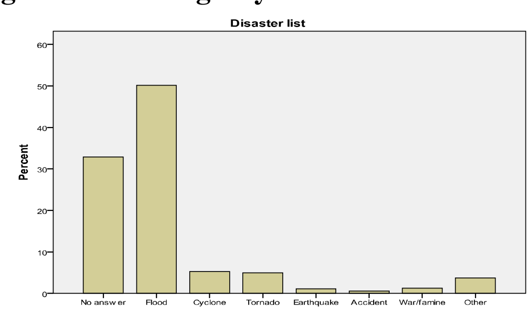


Figure-6: Experienced disaster list

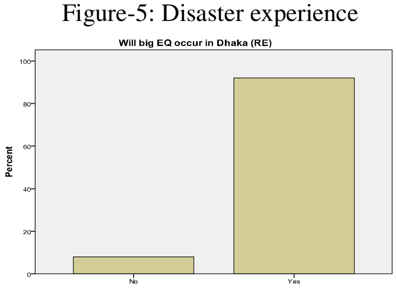


Figure-7: Anticipation of large earthquake

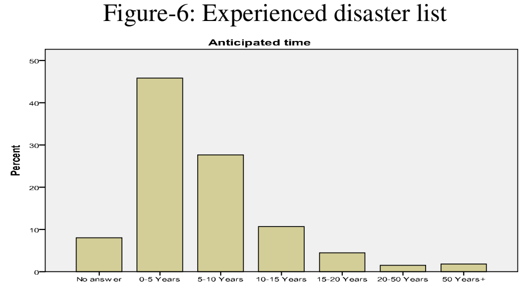


Figure-8: Anticipated time

Here we analyze the disaster experience and recognition of emergency of the respondents. As shown in Figure-5, we observed that 67.1% respondents have disaster experience in their lifetime in Dhaka. Figure-6 shows the consequent disaster list. About 50.1% respondents experienced flood. Only 1.1% people have experienced earthquake. Figure-7 shows that 91.9% respondents recognize the emergency of earthquake occurrence in Dhaka in near future. Figure-8 shows the anticipated time. Most of the respondents (45.8%) anticipate in 5 years time.

3.3 Risk Recognition (RR) and Acceptable Risk (AR):

Then we check the risk recognition of the respondents. Figure-9 shows the level of anticipated damage to the buildings in Moholla (adjacent local area). Figure-10 shows the same in Ward and Figure-11 shows in own house. For Moholla and Ward, we found that people fear for complete destruction, 45.6% for Moholla and 39.6% for Ward. The bar chart shows upward tendency for this two variables. But for the case of destruction level of own house, respondent increased more for 'no damage' (5.3%) or 'little damage' (20.1%), though complete destruction stands for 36.7%. In case of acceptable damage to own house, we found no extreme response. About 16.7% respondents expects 'no damage', 20.0% anticipated partial damage, which they can repair by themselves. On the other hand, 26.4% respondent fears for complete destruction and 21.1% respondents were not sure how much damage they can accept.

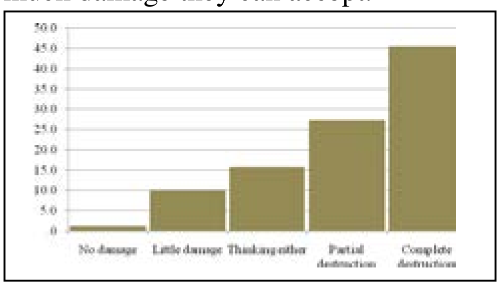


Figure-9: Damage in Moholla (%) (RR)

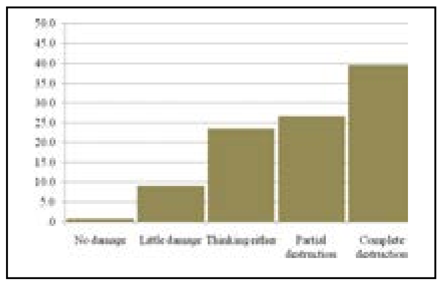


Figure-10: Damage in Ward (%) (RR)

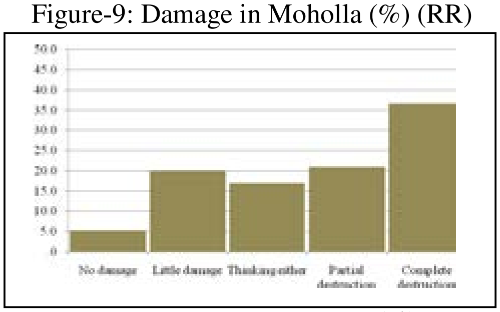


Figure-11: Damage in own house (%) (RR)

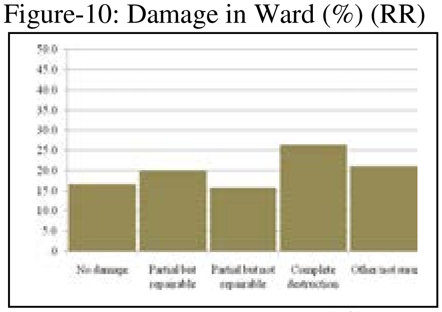


Figure-12: Acceptable damage (%) (AR)

3.4 Intention for safety measures:

In this section, we analyze resident's intention for safety measures. The proposition we made here is that if acceptable risk is lower than recognition of risk, then residents will intend for different alternative safety measures for their residence (Kato 2002). Figure-13 shows the result of intention, 36.9% respondent expressed their aim for retrofitting, and 34.2%

for repair. Though restoration is expensive, 18.5% people wish to adopt it. However, earthquake insurance is not that much popular in the context of Bangladesh, only 8.6% respondents expressed their desire for it. Figure-14 shows the causes for damaged house in big earthquake. Mainly three reasons are identified, which are responded in an upward trend. For example, 24.0% respondent thinks that cost cut or use of low cost materials will be the main cause while 28.6% thinks for lack of information i.e. information of earthquake vulnerability or following earthquake resistant design as specified in Bangladesh National Building Code (BNBC) 1993, and 32.6% think for built without following proper design or without engineering supervision. The two bar charts at the bottom show the willingness for pay for the intention of safety measures. Figure-15 shows that 58.9% respondent were not interested to pay for any safety measures, only 41.1% were intended. Then we informed them some specific earthquake disaster and risk information of Dhaka and some idea of expenses for safety measures. After that we repeated the same question of willingness to pay. This time we found change in their intention, which have been shown in Figure-16. About 50.8% respondent expressed their aim to pay for safety measures while 49.2% were still in negative position. Among them most of the respondents were tenants. The survey covered 49.6% of landlord and 49.6% of tenants. Tenants were not interested to pay for rent house’s safety measures.

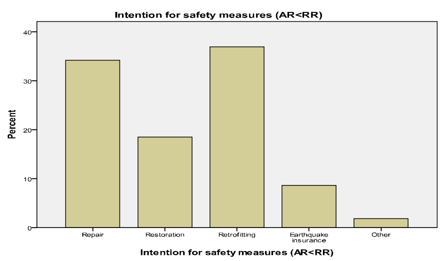


Figure-13: Intention for safety measures

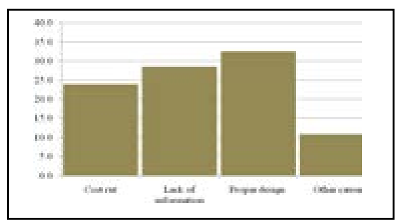


Figure-14: Cause of damaged house

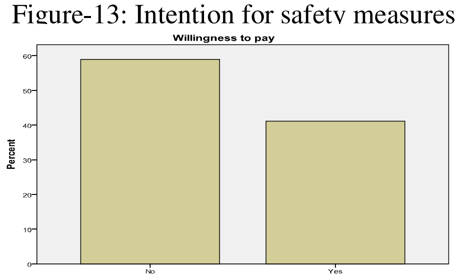


Figure-15: Willingness to pay (without info)

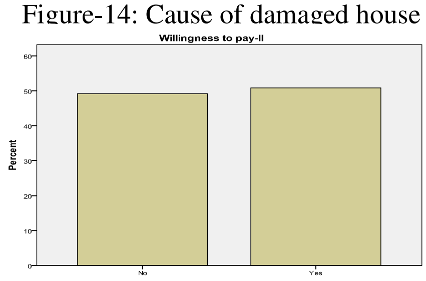
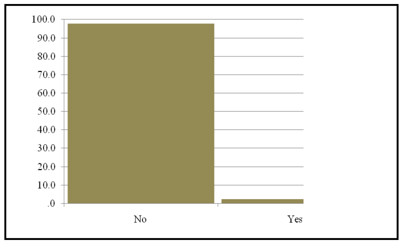


Figure-16: Willingness to pay (with info)

3.5 Knowledge on the BNBC 1993:

Here we explain respondents’ knowledge on BNBC-1993. Figure-17 shows the result. Only 2.4% respondents know about the BNBC-1993, and 97.6% respondents never heard about it. The result is too insignificant that it cannot be cross-analyzed. We only cross with educational qualification and as shown in Figure-18, we found that only some of the graduates know about it, but their idea is not specific. Therefore, people are not following the guidance of BNBC in construction or re-construction of buildings. This is one of the main causes of buildings constructed in an unregulated manner without earthquake consideration. Then we checked the present status of BNBC in construction practice.



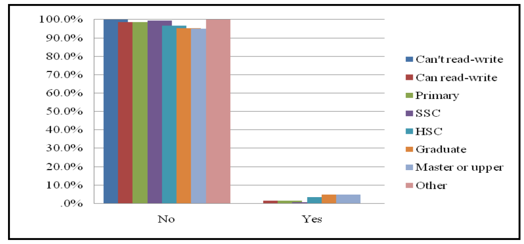


Figure-17: Know BNBC 1993   Figure-18: Know BNBC per qualification

4. BNBC 1993 AND CONSTRUCTION PRACTICE

4.1 Implementation status of BNBC 1993:

We had taken photos of respondent's houses. We analyze some of them to see the present status of implementation of BNBC. Photos shown in Figure-7 are some of the houses that's owner neither heard about the BNBC, nor could check if the design and construction had followed the BNBC or not. These houses did not follow the approved design too, for example, photo#1, 2, and 3 shows 'heavy overhangs' or 'short column' approach, which was not in design. Photo#2 shows that this house has been occupied before completion and without getting the 'occupancy certificate' from the concerned authority. Photo#4 is the entrance of the house shown in Photo#5, which also did not follow the proper design. Thus, as explained in section 3.4, most of the houses are constructed in Dhaka without following proper design (32.6%). In an interview, Housing and Building Research Institute (HBRI) informed that house owners in Dhaka, while constructing new buildings use two sets of design, one is approved design and another is working design, which is not approved. In this practice, we found the relation with cost cut, as explained in section 3.4 that 24% people believe that if the house is destroyed in big earthquake, cost cut will be the main cause. In between comes the response of lack of information, which we found 28.6% as the cause for destroyed house. Photo#6 is an old masonry type building, which followed old typical construction practice.

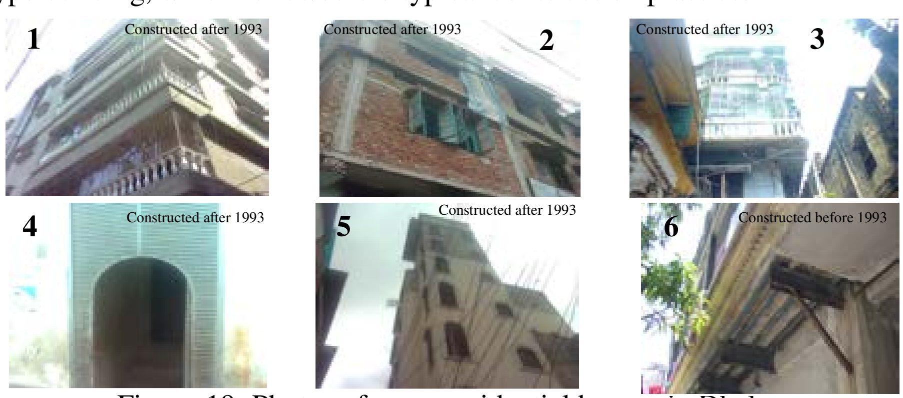


Figure-19: Photos of some residential houses in Dhaka

According to this study, 67% buildings were constructed before 1993. But the BNBC said nothing about them. It is not well circulated with common people's knowledge, thus they cannot check or monitor whether it is followed in construction or not. Based on this circumstance, common people should know about the basic guidelines of BNBC, so that they can implement or monitor the implementation of BNBC in construction and reconstruction practice. The BNBC 1993 came into effect with a gazette notification of the Bangladesh Government on November 15, 2006. It has been made mandatory to comply with in any building construction under the Building Construction Act of 1952 to ensure accountability in the management of overall building construction and safety of the buildings. As per section 2.1 of Chapter 2 of Part 1 of the BNBC 1993, the government is under obligation to establish a new or designate an existing agency responsible for the enforcement of this code with a given area of jurisdiction. However, the government is yet to set up any Code Enforcement Authority. Thus, absence of regulatory authority to care for all safety aspects of building as per BNBC is a major concern (Shafi 2010).

4.2 Interview with experts on implementation of BNBC 1993:

We have conducted four interviews on this issue with (1) the Vice-Chancellor of BRAC University, (2) Director, Bangladesh Network Office for Urban Safety (BNUS) of Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), (3) Director, Development Control of Rajdhani Unnayan Kartipakkha (RAJUK) [Capital Development Authority], and (4) Director, Housing and Building Research Institute (HBRI). The outcome of the interviews are explained below.

4.2.1 Interview with the Vice-Chancellor, BRAC University:

In reply to a question why only 2.4% people know about the BNBC, he said that the BNBC is not for the common people. It is for the use of the professionals. It was not needed for gazette notification by the government. The professionals should follow it while designing and constructing new buildings, and RAJUK should monitor all the steps. But he was worried that RAJUK is not doing this type of job as it does not have much capacity to do so. For the buildings constructed before 1993, he said that professional followed other standard construction guidelines like American or British construction code before the enforcement of BNBC in 1993.

4.2.2 Interview with the Director, BNUS:

In replying to the same question, the director said that common people need not to know about the BNBC. It is very sophisticated and prepared only for the professional engineers, who will be responsible for building designing and construction. He said HBRI could publish some easy version message or poster from BNBC. So that common people can understand and monitor while professionals work on the construction. In response to another question of why buildings do not legally follow BNBC during construction, the director said that it is very tough to implement this. RAJUK is responsible to implement the BNBC as a designated enforcing agency. But it does not have enough manpower to do so. He suggested that RAJUK should outsource this issue to outside developers initially for several years. By this time, RAJUK can develop its capacity. In replying to another question of how to ensure the capacity of buildings that were constructed before 1993, he said that BNBC does not have such provision of evaluating existing building's capacity. But the BNBC is going to be revised immediately. Direction for old and existing buildings and retrofitting guidance will be there. He said that the advantage of including BNBC under law is that it will ensure some punishment provision for those who violate the implementation. But the great disadvantage is that there is no authority to check this. He agreed with the question that local government should be included in the process of implementation of the BNBC.

4.2.3 Interview with the Director, RAJUK:

Director development control of RAJUK also thinks that common people need not to know about the BNBC. The structural engineer should be responsible for designing and implementation. He should issue a completion certificate and based on that RAJUK will issue occupancy certificate. About the building constructed before 1993, he said that RAJUK does not have much to do on that but some important social structure should be checked and improved their capacity to use in disasters. He does not think that local government can be involved in the implementation process of BNBC since they do not have any power and technical capacity.

4.2.4 Interview with the Director, HBRI:

The director HBRI said that common people should know the general idea of BNBC, but they need not to know more. It is for the technical person. People should know that they have to take a completion certificate from the technical person after completion of the building construction and an occupancy certificate from the concerned authority before they occupy the building to live. He said that he is not sure about the direction for the buildings that were constructed before 1993, but professionals would follow other standard code in designing and constructing buildings. He said that at present there is an evaluation program going on in Dhaka to check the status of buildings that were constructed before 1993. After getting the result, the government can take action for retrofitting if needed. House owner may also do some retrofitting which will be not much expensive. He said that BNBC should not be a part of law. It should be flexible for anytime revision. He also said that RAJUK should employ Building Officials for inspection and local government should be involved with the implementation process.

5. CONCLUSION

Dhaka is the fastest growing megacity in Asia with a high population growth rate (3.34%) (Shah 2009). The city is characterized by poverty, risk of natural hazards, shortage of housing, evacuation places and poor infrastructures. Dhaka's increasing population and expanding building structure will be subject to high risk in large earthquake. The paper checked inhabitant's risk recognition and intention for safety measures through a questionnaire survey. It described the following major results.

(1) Inhabitants anticipate earthquake as the most catastrophic disaster for Dhaka, which may occur in 5-10 years time;
(2) Building without proper design and engineering supervision will be the main cause of destructed house in large earthquake;
(3) BNBC 1993 is the guideline for earthquake resistant construction, but it is not followed accordingly as mass people are not aware;
(4) Inhabitants recognized risk and acceptable damage for their buildings. They showed their willingness to pay for safety measures of their buildings.

REFERENCES

Ansary, M.A., and Rashid, M.A., 2000. Generation of Liquefaction Map for Dhaka, Bangladesh, paper presented at *8th ASCE Special Conference on Probalistic Mechanics and Structural Reliability*, University of Notre Dame, Indiana, USA.

Ansary, M.A., 2004. Seismic loss estimation of Dhaka for an earthquake of intensity VII. *Oriental Geographer*, Vol. 48, No. 1, January 2004

Al-Hussaini, T.M., 2003. Critical Elements for Earthquake Disaster in Dhaka City, paper presented at *USMCA 2003 Symposium on New Technology for Urban Safety of Mega Cities in Asia*, Tokyo, Japan.

Bilham, R., and England, P., 2001. Plateau 'pop-up' in the great 1897 Assam earthquake, *Nature*, 410, 806-809.

Hossain, Shahadat, 2008. Rapid Growth and Poverty in Dhaka City, Bangladesh e-Journal of Sociology, v. 5, no. 1, Dhaka, Bangladesh.

Kamal, A.S.M. Maksud, and Midorikawa, Saburoh, 2004. GIS-based geomorphological mapping using remote sensing data and supplementary geoinformation: a case study of the Dhaka city area, Bangladesh. *International Journal of Applied Earth Observation and Geoinformation*, v.6 (2004), p. 111-125.

Kato, Takaaki, Komiya, Mitstoyo, Kameno, Hiroaki, Sakei, Takuma, Murao, Osamu, Ymazaki, Fumio, Kobiyama, Masayuki, 2002. "Understanding the Local Characteristics of Earthquake Risk Awareness of Residents in Sumida and Setagaya", Proceedings of the Japan Earthquake Engineering Symposium, Vol. 11, 2423-2428 (in Japanese).

Shafi, Salma A, 2010. Implementation of National Building Code, paper presented at Rights Workshop at National Press Club of Dhaka, Bangladesh.

Shah, Md. Faiz, and Murao, Osamu, 2009. A comparative study of urban vulnerability between Dhaka and Tokyo, paper presented at *USMCA 2009 Symposium on New Technology for Urban Safety of Mega Cities in Asia*, Incheon, Korea.

Application of Cluster Method on Integrated Risk Analysis in a Building Fire

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ABSTRACT

With fire development and smoke propagation, occupant lives are threatened by the dreadful environment, made up of high-temperature, smoke, carbon monoxide, carbon dioxide, etc. It is crucial to analyze the fire condition and optimize the evacuation strategies to win the time for occupant evacuation. But the adverse effect cannot be intuitionistic described by a mathematical model. So a multi-variable statistics method is used to analysis the coupled effects of all the factors. Using the two-step cluster analysis method, multi-factor injury risk can be evaluated considering adverse effect of high temperature, carbon monoxide and lack of oxygen. Fire simulation experiments have built a virtual fire information platform to provide data for risk calculating and the multi-dimension data set can be grouped automatically by calculating the similarity of space state and danger state or safety state using the likelihood distance function. And a dynamical risk map is generated to show the state of fire development and smoke propagation. l. The model can get a dynamic integrated fire risk map, adverse factor range for every risk level, etc. to support evacuation command and control.

Keywords: Two-step cluster; Building fire; Injury factors; Fire risk

1. INTRODUCTION

Decorated materials, furniture and office stationary in a modern building contain some kinds of chemical ingredients. In a fire, those elements can produce many harmful substances such as high temperature smoke, carbon monoxide, carbon dioxide, etc., which can affect the safety of the occupants. To make an effective rescue plan, hazard level of every zone in a building should be analyzed dynamically. Injury risk analysis in a fire space is a multi-factors problem. At 85℃, three degree burn injury can be formed in 10s (Cooper etc., 1985). Too high concentration of carbon monoxide and carbon dioxide can harm the ability of judgment and movement (Li Y Q, 2005). And impact on human of high-temperature, smoke, carbon monoxide, carbon dioxide, etc. can be coupled with each other. The factors can reduce a person's capability of judging, acting and memory. Kataoka has explored the influence of high temperature of 40℃ on the change of heart rate variability and blood pressure (2005); Yu Xuejun focused on the thermoregulatory, cardiovascular, pulmonary, biochemical and molecular biological responses of man to heat stress (2000). But there is no sufficient medical data and the adverse effect cannot be intuitionistic described by a mathematical model. To solve the problem, multi-statistics method may be useful to fill up the deficiency and the integrated fire risk level can be got by the comparison of similarity of space state and danger state or safety state. With the development of information and sensor technology, various sensors have been installed in the building. It is possible to generate a risk map in a building fire utilizing sensor information. Such map will be important for occupant evacuation and rescue planning.

In this paper, to demonstrate the function of algorithm, the fire risk algorithm has been applied in a typical building. Instead of real sensor data, fire simulation is performed to build an information platform to provide the necessary information for risk calculating. An integrated risk map can be determined in a building fire through information data classification by the likelihood distance measure. The results can be useful to make evacuation and rescue decisions and make proper emergency measures.

2 PROBLEM SETUP

An algorithm will be developed in the paper to discuss the fire risk map in a typical building, shown as Figure 1. The office zone is usually divided into several rooms by office divisions based on tenement requirements. Every office zone has at least an exit to the corridor. In the building, the office zone is about 900 m^2. the height of building is 2.7 m. Smoke extraction vents lie in the ceiling shown as Figure 1. Locations of doors and walls are shown in Figure 1. The fire is assumed to occur in zone 25. Fire simulation will be used to generate a fire scenario and sensors are assumed to locate in the office zones shown as Figure 1.

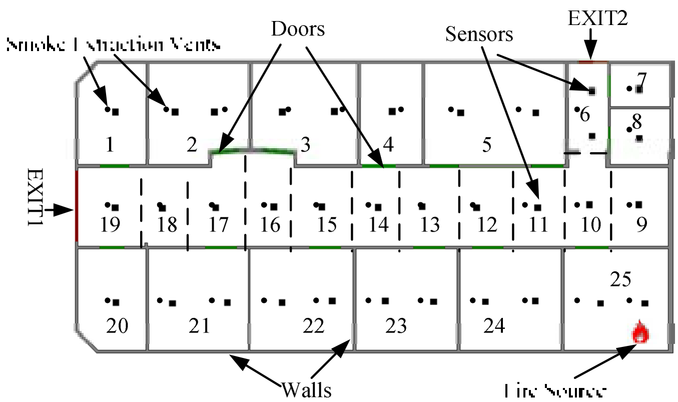


Figure 1: Fire simulation model

3 FIRE RISK EVALUATIONG ALGORITHM

With fire development and smoke propagation, various sensors, information related to fatal factors, such as temperature, toxic material concentration, etc. can be obtained and form an information network $G(E, A)$, where the sensor location is denoted by set $E = \{e_1, e_2, \cdots, e_n\}$ and the information type is represented by A. If temperature, carbon monoxide and oxygen concentration are selected as information characteristic values, the information type set will be described as $A = \{T, CO, O_2\}$. Risk of each zone at every time can be analyzed using a two-step cluster method.

3. 1 Fire risk analysis algorithm based on two-step cluster method

At present, most of fire risk analysis models focus on the impact of a single fatal factor and cannot show the integrated impact of multiple factors. A multi-variable statistics method is needed to realize analysis of multi-dimension data set. The two-step cluster analysis method, a multivariable statistics method, can group the multi-dimension data set automatically by distance. Using the method, the integrated fire risk map can be obtained based on sensor information which is made by some fatal factors such as smoke temperature, oxygen concentration, carbon monoxide concentration, etc. With this method, fire risk can be obtained to optimize evacuation path.

(1) Construction of the cluster feature tree (CFT)

During the course of constructing the cluster feature tree (CFT), first step is to search class centers. All the measured data is reviewed to ensure the class center and a likelihood distance is used as similarity measure criterion. The measured data can be classified by the similarity measure with nodes in CFT and become a new node of the tree. Finally CFT tree can be constructed. The safe criterion sample and dangerous criterion sample are selected as two class centers. And the classification information includes three continuous variables. The likelihood distance can be calculated by the logarithm likelihood function as follows:

$$d(i, s) = \xi_i + \xi_s + \xi_{(i,s)} \tag{1}$$

$$\xi_i = -n_i \left(\sum_{j=1}^{p} \frac{1}{2} \log\left(\hat{\sigma}_{ij}^2 + \hat{\sigma}_j^2\right) - \sum_{j=1}^{q} E_{ij} \right) \tag{2}$$

$$E_{ij} = \sum_{l=1}^{m_j} \hat{\pi}_{ijl} \log(\hat{\pi}_{ijl}) \tag{3}$$

Where, σ_{ij}^2 variance of continuous variable $w_{ia_j}^{kT}$; π_{ijl} the probability of variable having L value in zone k.

(2) Bayesian information criterion (BIC) classification

Second step is to group leaf node in CFT using bayesian information criterion (BIC). If $BIC_k / BIC_1 < 0.04$, K is the cluster result of every node. BIC_k can be got as follows :

$$l_k = \sum_{v=1}^{k} \xi_v \tag{4}$$

$$BIC_k = -2l_k + r_k \log n \tag{5}$$

Where, l_k is the maximum value of likelihood function; r_k is number of model parameter $r_k = k \times (2p + \sum_{k=1}^{q} n - 1)$.

3.2 Zone risk calculating

Risk level of every sensor in the zone has been obtained by two-step cluster analysis. And zone fire risk can be got by risk level probability calculation. Zone fire risk can be calculated as follows:

$$Risk^{'} = \sum_{i=1}^{3} risk_i \times p(risk_i) \tag{6}$$

Where, $Risk^{'}$ is zone fire risk ; $risk_i$ the risk level of some sensor in the zone ; $p(risk_i)$ is the probability of the risk level $risk_i$ in the zone , $p(risk_i) = NUM(risk_i)/n$.

4 EXPERIMENT RESULTS AND DISCUSSION

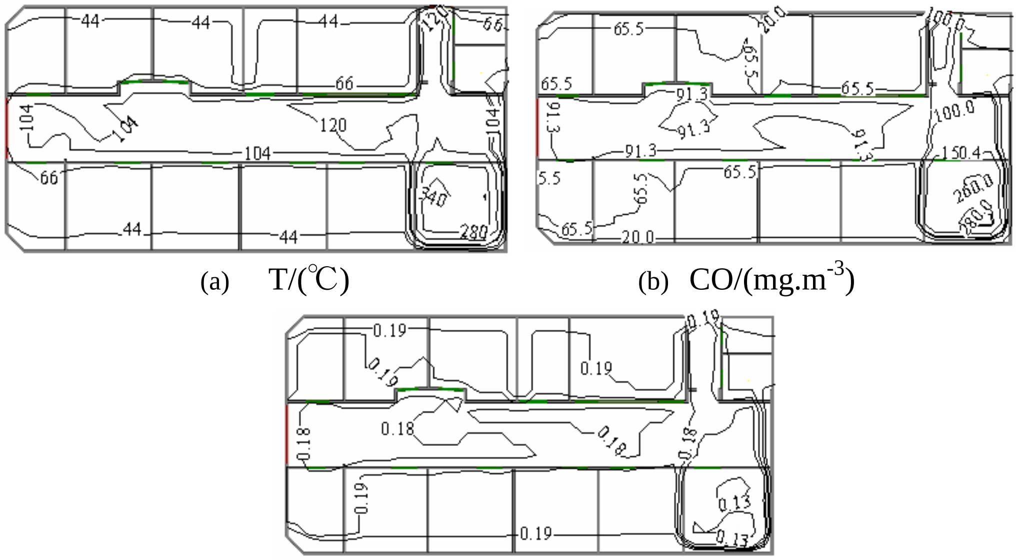
The purpose of this paper is to generate the dynamical risk mapping during the fire if the information is available. It is noted that in reality, only part of information can be obtained. Such study will provide the maximum possibility in occupant safety using fire information from simulation results. High temperature, carbon monoxide poisoning and lack of oxygen are selected as characteristics of fire risk. Fire risk evaluation method is applied to the building as shown in Figure 1. The fire risk is set to be four levels, e.g., safe, low risk, moderate risk, and high risk, indicated as levels 1~4. Information type will be set as {T, CO, O_2}. Safe or high risk criterion is selected according to criteria such as NFPA101 and Japanese building fire protection design, evacuation and refuge safety design method, etc. Most dangerous criterion parameter value is set as (80, 150, 0.15). Normal indoor state is selected as the safest criterion parameter value, which is (20, 0, 0.25).

4.1 Fire simulation results

FDS from NIST is selected for fire simulation. Fire source is assumed to be the propane gas combustor and located at the right top of the floor. Fire source is located in the floor and the area is about 4 m^2. Fire location is shown in Fig. 1. Office fire is developed under sprinklers and smoke extraction equipments action. Meshes are divided using the non-uniform partitioning method. The total number of mesh is 100×50×12. Simulation time is 1800 s. Fire heat release is assumed to be developed according to t^2, heat release can be obtained as follows:

$$Q = 0.0469 \times t^2 \quad (7)$$

The maximum fire power is set to be 2MW and fire develops to the maximum fire power at 180 s. Average temperatures, carbon monoxide concentrate and oxygen concentrate distribution at 1.8m height in 500 s is shown as Figure 2.



(a) T/(℃) (b) CO/(mg.m^{-3})

(c) O_2/(%)

Figure 2: (a) Temperature; (b) carbon monoxide concentration; (c) oxygen concentration distribution at 1.8m height.

4.2 Multi-factors fire risk analysis

Using simulation results as sensor information, building risk can be analyzed using the risk evaluation model. Factors importance was be ranked by significance testing. The risk of each zone and fire risk map can be obtained.

(1) Ranking of variable importance

An integrated risk map is generated based on evaluating the influence of high temperature, too much carbon monoxide and lack of oxygen. Every factor has different importance to risk analysis. By significance test, the importance of every variable to high risk cluster can be sorted. Significance test is performed to determine if an observed variable of statistics differs enough from the overall data set. A p value is reported for the test of probability of a variable with the significance different in the overall data set. And a tolerant confidence level p should be set for the test of probability of a variable's distribution within high risk cluster results versus the overall variables.
Figure 3 were plotted to show the importance rank of each variable. And a tolerance confidence value is set as 95, shown as vertical lines in Figures 3. From the figure, it is shown that weather the importance of the variables reaches the specified confidence level. From the plot, it is shown that CO is obviously more important at the early period of fire. With fire developed, temperature becomes the key factor gradually. At 500s, significance of all the factors is beyond the confidence level. Fire risk map should be developed based on all types of sensor information.

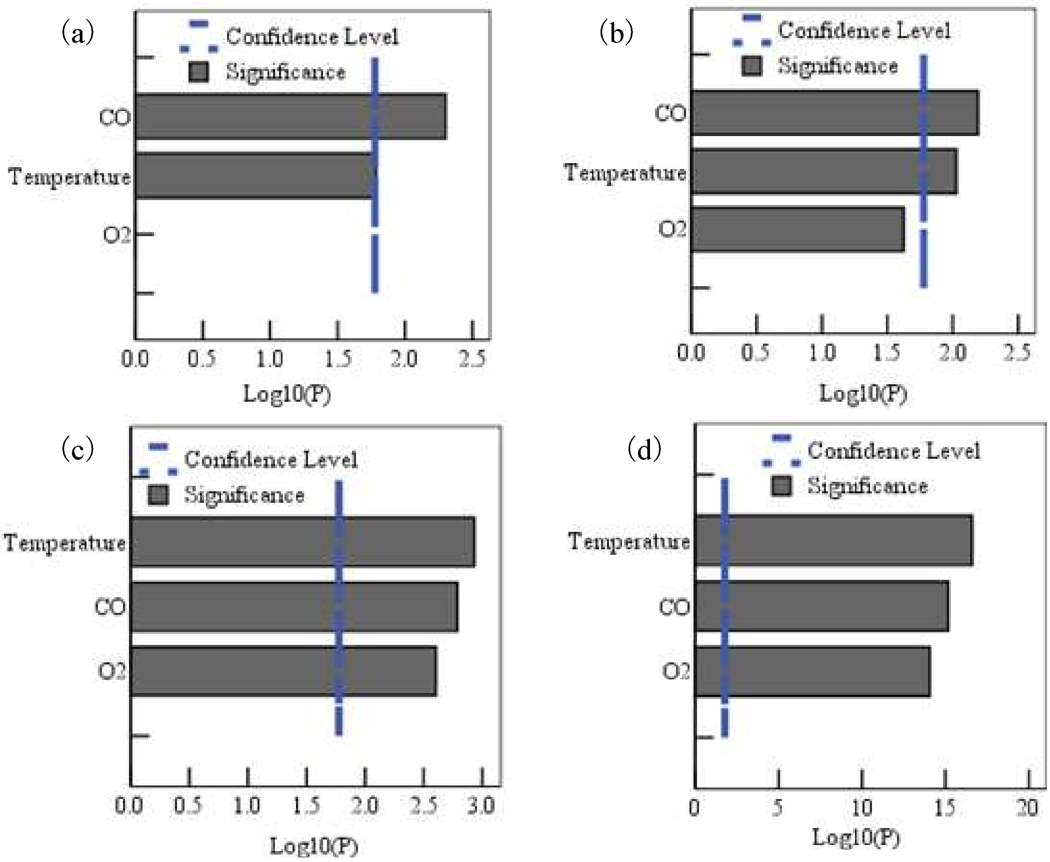


Figure 3: Ranking of importance at (a) 100s; (b) 200s; (c) 350s; (d) 500s

(2) Fire risk analysis by two step cluster

In case of a fire in zone 25(shown as the red zone in Figure 4(a)), smoke will propagate along the ventilation network of building (shown as Figure 4), Based on the virtual fire information platform by simulation results, integrated risk assessment was applied to the building, shown as fig. 1. temperature, CO and O2 were selected as indexes and risk assessment results of room with fire, the room and corridor neighbor fire room at 100 s～400 s are shown as Figure 4 (a).

At 100 s, fire is at the early stage of development. The change of temperature, CO and O_2 concentration of the room with fire and the corridor neighbor fire room are greater than other rooms. So the adverse environment of the room with fire may cause person causality. By calculated, risk level of the room with fire and the corridor neighbor fire room are low risk and other rooms are safe because the high-temperature smoke has not be propagated to them. At 200s, temperature and toxic content of room with fire are increased and oxygen content is decreased rapidly with the development of fire. The probability of injury persons of high temperature and other adversities of room with fire and the corridor neighbor fire room is high relative to other rooms. By calculated, risk level of the room with fire is high risk and the corridor neighbor fire room is moderate risk and other rooms are low risk. At 500s, with smoke propagation, the corridor neighbor fire room is dangerous. The state of the corridor is similar to fire room than other rooms. By calculated, risk level of the room with fire and the corridor neighbor fire room are high risk and other rooms are moderate risk. An integrated fire risk map at 100s, 200s, 350s, 500s by multi-factor analysis has been generated shown as Figure 5. From Figure 5, it is shown that the rooms of the building gradually become dangerous with the smoke propagation from fire room to the corridor and the other rooms with development of the fire.

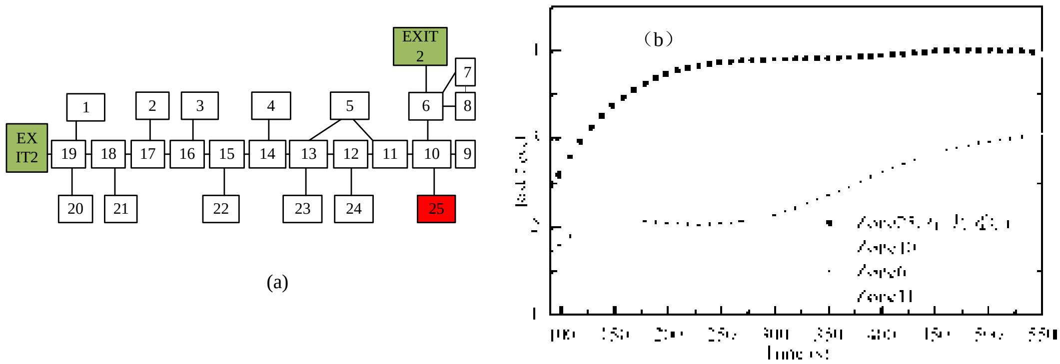


Figure 4: Risk evaluation results of zones. (a) Smoke Propagation Network; (b) risk evaluation result of zones.

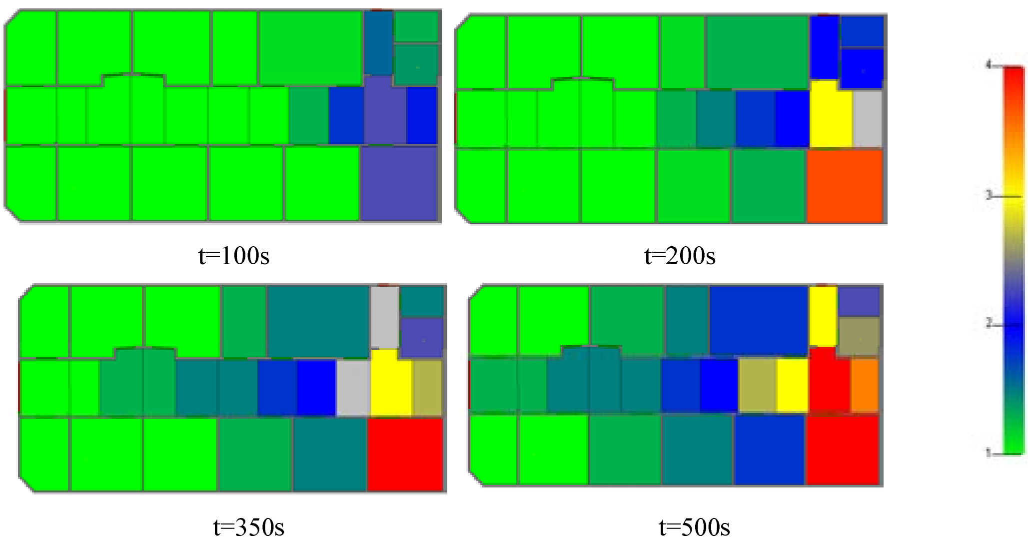


Figure 5: Fire risk map of building at 100s, 200 s, 350 s, 500s

5 CONCLUSION

Fire risk evaluation algorithm has been developed to generate fire risk map utilizing sensor information. It can generate a fire risk map considering adverse effect of high temperature, carbon monoxide and carbon dioxide, and realize the transformation of real-time signal to visualization risk distribution. The fire risk map is a comprehension result of multi-factors influence and conforms to the development of fire. It is the intuitionistic presentation of the impact on human by fire. And the risk map is useful to grasp the development of fire. Factuality of the method depends on the type and amount of the information. Information requirements should be analyzed to get an optimum fire risk map.

ACKNOWLEDGEMENT

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REFERENCES

Purser D A. Toxicity assessment of combustion production. SFPE handbook of fire protection engineering, National Fire Protection Association, Quincy, Massachusetts, Third edition, 2002

Cooper L Y, Stroup D W. ASET-A computer program for calculation available safety egress time. Fire Saf J 1985;9 (1) : 29–45

Li Y Q. Building Fire Performance-based Design. Beijing: Chemical Industry Press, 2005

Kataoka Y, Yoshida F. The change of hemodynamics and heart rate variability on bathing by the gap of water temperature. Biomed Pharmacother 2005; 59: s92—s99

Yu Xuejun. Human Physiological reactions to Heat Stress in Space Flight. XiAn：Fourth Military Medical University,2000

Zhang Guogao. Biology and Health in High Temperature. ShangHai: ShangHai, Science Technology Pr, 1989

Liu Naian, Liu Qiong, Deng Zhihua, et al. Burn-out time data analysis on interaction effects among multiple fires in fire arrays. P Combust Inst, 2007; 2:2589-2597

Chu Yanyan, Zhang Hui, Rui Yang, et al. Simulation Study on Building Fire Smoke Control Strategy Based on Fire and Occupant Information. J Tsinghua University 2010; 8:1-7

Chu G Q, Sun J H. Decision analysis on fire safety design based on evaluating building fire risk to life. Safety Sci 2008;46(7): 1125– 1136

CHU Yanyan, ZHANG Hui, et al. Development a mode to generate a risk map in a building fire. Sci China Ser E-Tech Sci 2010; 2(53):1-9

Zhu Y C. Application of two step cluster model (in Chinese). Market Res 2005;1:40–42

Emerging web and geospatial technology revolutionizes disaster response with public involvement

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ABSTRACT

This paper examined how disaster response and relief efforts changed in recent years, driven by new web-based geospatial technologies. The purpose of this article is to examine how disaster response and relief efforts have been changing along with recent geospatial technological development, mainly from Haiti earthquake response in 2010. This paper outlined how conventional disaster responses used GIS, which were mainly provided by government agencies and non-profit organizations; and how they have been transformed into a more dynamic, transparent and decentralized process with broader participation. The paper started with a brief overview of historical changes in the utilization of geospatial technologies in major devastating disasters, including the Haiti earthquake in 2010. We documented changes in available geospatial dataset types and responders, examined new trends in data creation, management, sharing and visualization; analyzed the impact of geospatial technology development on relief efforts; discussed lessons learned from recent disaster responses; and shared our thoughts for future improvement.

Keywords: *web-mapping, public involvement, crowd-sourcing, disaster response, Haiti earthquake*

1. INTRODUCTION

Mortality and direct economic loss appear to be highly concentrated geographically and associated with a very small number of disasters (ISDR, 2009). Five of the ten disasters with the highest death tolls since 1975 have occurred in just the last five years1. Also, five of the ten disasters with the highest economic loss have occurred in the last six years1. Management and use of maps and location information were critical for effective response activities in many of these disasters. The approach of disaster response and relief efforts has been changing with the current development of geospatial technologies such as Geographic Information System (GIS), Remote Sensing, and Global Positioning System (GPS).

In conventional geospatial response to disasters, mapping activities were conducted mainly by professional geospatial groups from governmental agencies, relief response organizations and GIS vendors in support of decision making on the ground. Damage information was intensively collected and decision-support maps were created, edited and printed at a centralized emergency operation center in the damaged areas using desktop and workstation GIS systems, and information was disseminated in top-down manner. However, in addition to conventional centralized disaster response by professional groups, recent development of web mapping technology has led to more dynamic, more transparent, and more decentralized disaster response supports conducted with a wider range of participation, including both formal and informal individuals and organizations from both inside and outside the damaged area. This movement started to emerge in the disaster response during the Chuetsu earthquake in 2004, and during Hurricane Katrina in 2005 it was further developed with additional technological development and the changes in social awareness. Finally, its form was fully revealed in the Haiti earthquake in January 2010.

The purpose of this paper is to outline how disaster response and relief efforts have been changing along with recent web-based geospatial technological development, mainly from the Haiti earthquake response, and investigates which factors of these technological developments affect disaster response support. Although emerging interactive information technologies such as wiki, Twitter, and blogs are also playing important roles for recent disaster response and relief efforts (Mills et al., 2009, Zook et al., 2010, Underwood, 2010), this paper focuses on outlining how web-based geospatial technological development has been changing approaches to disaster response and relief effort.

At the beginning, historical changes in the utilization of geospatial technologies in major devastating disasters are briefly reviewed until the Haiti earthquakes in 2010. We examine the change in available dataset type and geospatial disaster responders, then the impact of geospatial technological changes on disaster relief effort are examined in order to investigate which factors of the technological developments affect disaster response support. Finally, the paper discusses lessons learned from recent responses and some thoughts for future development.

2. MAJOR CHANGES IN DISASTER RESPONSE

For the most part, it’s generally assumed that government or other relief entities such as the United Nations are the primary actors in disaster response and relief, with NGOs playing a secondary role. However, public interest and demand for geospatial information in disaster response and relief has been rapidly increasing, and the opportunity for volunteers to assist in disaster response via mapping and spatial analysis has significantly grown along with geospatial technological development. This section describes how development of web-based geospatial technologies has affected the awareness and involvement of a wide range of disaster response participants.

2.1 Availability of aerial and satellite imagery from the private sector

Regarding satellite and aerial remote sensing imagery, the tendency to provide high-resolution (high-res) satellite imagery to the public for free has been increasing, not only by space agencies and institutes in various countries, but also by commercial companies (Table 1). Nowadays, observation frequency of sensors and satellites is increasing year by year. Within five days of the earthquake in Haiti, many high-res satellite images from more than 15 organizations in eight countries were collected and made freely accessible at the websites of the International Charter, UN-SPIDER, etc. The list of remote sensing imagery used for the Haiti earthquake is shown in Table 1. The quality and quantity of available satellites and sensors have greatly increased since the time of the World Trade Center attacks in 2001. In Haiti, more than half of the satellite data providers were commercial companies from various countries such as DigitalGlobe and GeoEye from USA, RapidEye from Germany, and SpotImage from France. Some organizations such as DigitalGlobe and NIED (National Research Institute for Earth Science and Disaster Prevention) and JAXA (Japan Aerospace Exploration Agency), distributed acquired imagery using their WMS (Web Map Service) server, which enabled users to easily obtain and use this geospatial datasets, including the ability to deploy them in their own web mapping applications and mashups.

Table 1: Remote sensing imagery used during the Haiti earthquake in 2010

Data provider	Satellite	First dates of acuirement	Business type	The use at OSM
NOAA (National Oceanic and Atmospheric Administration), USA	Cessna Citiation II (aircraft)	1/18	Non commercial	+
GeoEye, Inc., USA	GeoEye-1	1/13	**Commercial**	+
	IKONOS	1/17		
DigitalGlobe, Inc., USA	QuickBird	1/15	**Commercial**	+
	WorldView-1	1/14		
	WorldView-2	1/15		
EROS (Earth Resources Observation Satellite) Corp., US and Israel	EROS B	1/17	**Commercial**	+
CNES (Centre National d'Etudes Spatiales) and Spot Image, France	Spot 5	1/14	Non commercial	+
SpotImage	Formosat-2	1/13	**Commercial**	
NIED (National Research Institute for Earth Science and Disaster Prevention), and JAXA (Japan Aerospace Exploration Agency), Japan	ALOS	1/23 (Pan-sharpened) 1/23 (PRISM) 1/13 (AVNIR-2) 1/16 (PALSAR)	Non commercial	+
e-GEOS S.p.A., Italy	COSMO-SkyMed	1/15	**Commercial**	
MacDonald, Dettwiler and Associates Ltd., Canada	Radarsat-2	1/14	**Commercial**	
China	HJ-1-A/B	1/14		
RapidEye AG, Germany	RapidEye	1/13	**Commercial**	
Infoterra GmbH, Germany	TerraSAR-X	1/14	**Commercial**	
NASA, USA	Earth Observing One (EO-1)	1/15	Non commercial	
European Space Agency, European Union	ERS-2		Non commercial	
	Envisat			
KARI (Korea Aerospace Research Institute, Republic of Korea	KOMPSAT-2	1/15	Non commercial	

Resolution of satellite images and aerial photographs has been improving and even made it possible to identify damaged areas or blocked roads. After the Kashimir earthquake, high-resolution images created controversy due to concerns that national security could be compromised in the region where Pakistan and India have long fought (Butler, 2005a, Butler, 2005b) . However, the use of high-res satellite imagery is absolutely imperative for response to devastating disasters. Following the Haiti quake, many high-res satellite sensor images were made available and used to create OpenStreetMap features. In this case, volunteers viewed the imagery within the webmap mashups (such as the Haiti CrisisMap), then logged in with editing privileges to trace new features over the imagery or to add textual annotations in the same mashup application (OpenStreetMap, 2010, Zook et al., 2010).

2.2 Emergence of new geospatial responders

The largest change in awareness of geospatial response has been the increase in people willing to participate via the Internet (Zook et al., 2010, Laituri and Kodrich, 2008, Underwood, 2010, Mills et al., 2009). This includes individuals and organizations, professionals and amateurs, and people from both inside and outside the damaged area. Traditionally, government agencies tend to depend on their own internal information for the decision-making in response and relief effort, but now the government is accepting external datasets created by non-authorized people from outside the damaged area for decision-making. OpenStreetMap data was broadly used by multiple agencies and NGOs on the ground in Haiti; in fact, voluntarily-created geospatial information played a critical role in emergency response. This is especially true for volunteer labor. Crowd-sourced mapping allows aid agencies to focus their limited resources on other needs that cannot be easily met via distributed volunteer workers (Zook et al., 2010). This has led to the development of a kind of divisional cooperation between those inside and outside the damaged area, individuals and organizations, and experts and amateurs, and has changed the available dataset types and geospatial responders as shown in Figure 1.

In many traditional disaster responses, prepared “GIS base maps” (mainly used for daily work) such as buildings, land-use, critical infrastructure, and transportation network were used as the core data source for emergency response by overlaying these maps with the actual “damage information on the ground” collected through patrols, calls from citizens, or “remote sensing imagery” taken after the event, with professional geospatial response teams in charge of the entire geospatial operation (Figure 1). The professional teams generally consist of a “GIS specialist” for editing vector datasets and analyzing and producing maps for supporting decision-making; a “remote sensing specialist” for georeferencing and processing satellite and aerial imagery; a “database specialist”; a “project coordinator”; a “field data collector” who collects damage information and response progress on the ground using hand-set equipment with GPS; and a “web specialist” for setting up a web mapping server and creating web applications. They are primarily composed and managed by governmental agencies, relief response organizations, GIS software venders, and organized volunteer groups such as the above-mentioned GISMO in New York City, and mainly work at a centralized emergency operation center on-the-ground.

Besides the traditional response participation by government agencies and relief response organizations, the general public's involvement in response activities via the Internet has been growing drastically with the emergence of new technologies, resulting in the emergence of a new style of disaster response – a networked disaster response community – in addition to the traditional professional response team as shown in the gray zone in Figure 1. These communities are comprised of formal and informal networks of people collecting, processing, and delivering information where it is needed.

Plenty of actual damage information on the ground was disseminated by the ad hoc citizen groups, local victims of the event and their families, and computer-based disaster response volunteers who collected and disseminated data in the form of text, blogs, video, pictures and maps (Laituri and Kodrich, 2008). "Field data collectors" provided actual "damage information on the ground" through their mobile phones using SMS (Short Message Services) or GPS cell phones with cameras. For example, the Ushahidi project disseminated victim's reports as mapped information about the suffering families, damaged housing and needs for food sent via SMS from mobile phone. Such live information reportage included items such as: children trapped in a collapsed school screaming for help; an 80-year-old woman with a crushed leg who needed evacuation; the location of a drum of water-purifying solution (Smith, 2010). These real-time updates on where help was most urgently needed or available -- originating as a wave of 20,000 text messages and then mapped as 3,500 incidents -- helped to save lives and get crucial aid to thousands of Haitians in the weeks after the quake (Smith, 2010, Provencher, 2010).

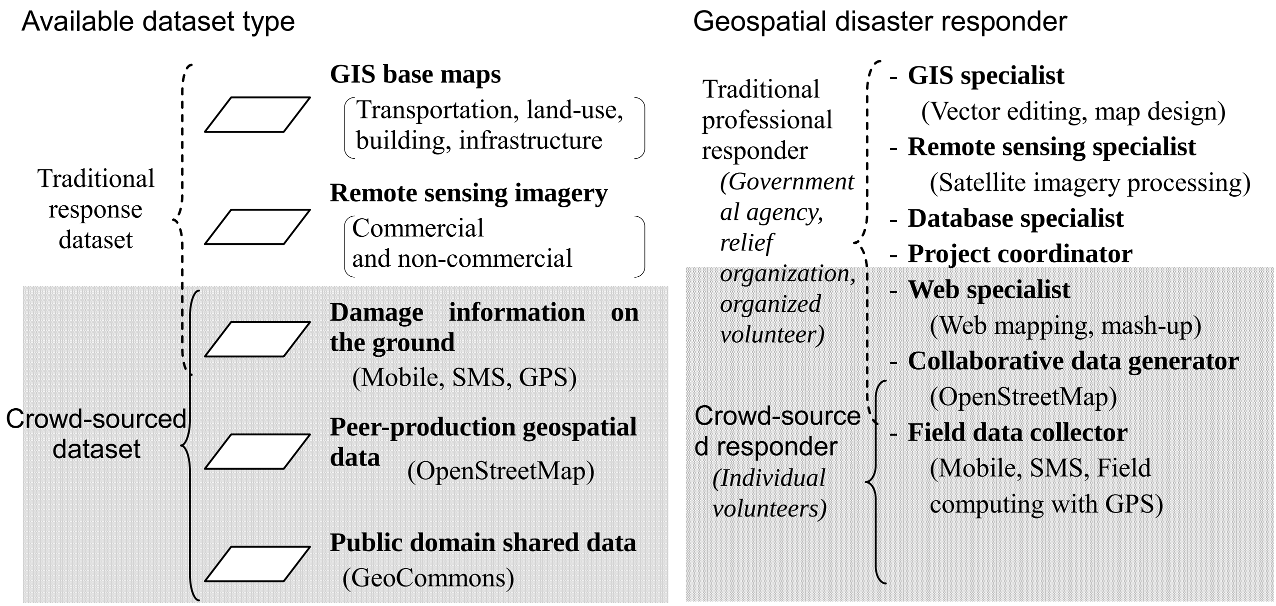

Figure 1: Change in available dataset type and geospatial disaster responders

As a “collaborative data generator”, OpenStreetMap has played an important role in the response activities in Haiti. OpenStreetMap is a project to create free “peer-production geospatial data” such as road and railway networks available for use by anyone through the web. Thousands of volunteers from outside the country joined the project to create and edit maps on a wiki-like environment. Within a few days of the Haiti earthquake, OpenStreetMap community started to help the response teams by tracing Yahoo imagery and other data sources and created various datasets on the island such as roads, railway, waterways, place names for towns, and buildings including damage assessment information. Extracts of these frequently updated datasets for Haiti are also downloadable in OpenStreetMap as source files, Garmin GMAPSUPP.IMG files, and ESRI shapefiles. The details of this activity are described by Zook et al.(2010).

As a “public domain shared data” site, GeoCommons was used to promote geospatial data sharing on the web. This allows us to upload, organize and share geospatial data and to quickly find data with easy search tools. It also has functions for visual analytics through maps which require no prior training or experience using traditional mapping tools. At GeoCommons, new contents were uploaded or downloaded in KML, CSC or shapefile formats. GeoCommons can be a powerful platform for data management and sharing with visualization functionality as well as analytic features because it has both raw data sharing function for researchers and professionals, and provides visualization and analytical tools for the general public. Crowd-sourcing is not limited to amateurs, and the GeoCommons project illustrates how institutions can crowd-source their internal data to facilitate better data sharing and collaboration (Zook et al., 2010).

3. RELATIONSHIP BETWEEN WEB-BASED GEOSPATIAL TECHNOLOGICAL DEVELOPMENT AND CHANGE IN DISASTER RESPONSE SUPPORT

It is said that “the year 2005 was a watershed for GIS on the Internet” (Butler, 2006), and there have been many major technological developments since then. We believe this affected awareness over a wide range of participants in devastating disaster response in terms of available datasets and geospatial responders. Through the response activities for the three recent devastating disasters in Sichuan, Haiti and Chile, we found that current web-based geospatial technology development has been changing the way disaster response and relief efforts are conducted. The Haiti earthquake is the first disaster in which open-source, online platforms are being heavily utilized (Forrest, 2010, Zook et al. 2010). This section describes three incremental stages of web-based geospatial technological development, namely “web mapping and geospatial data browsing,” “web-based data exchange and development,” and “mash-up live editing on the web”. The timeline of this technological development and devastating disaster history and the total image of the impact of web-base geospatial technological changes on disaster response effort, are shown in Figure 2.

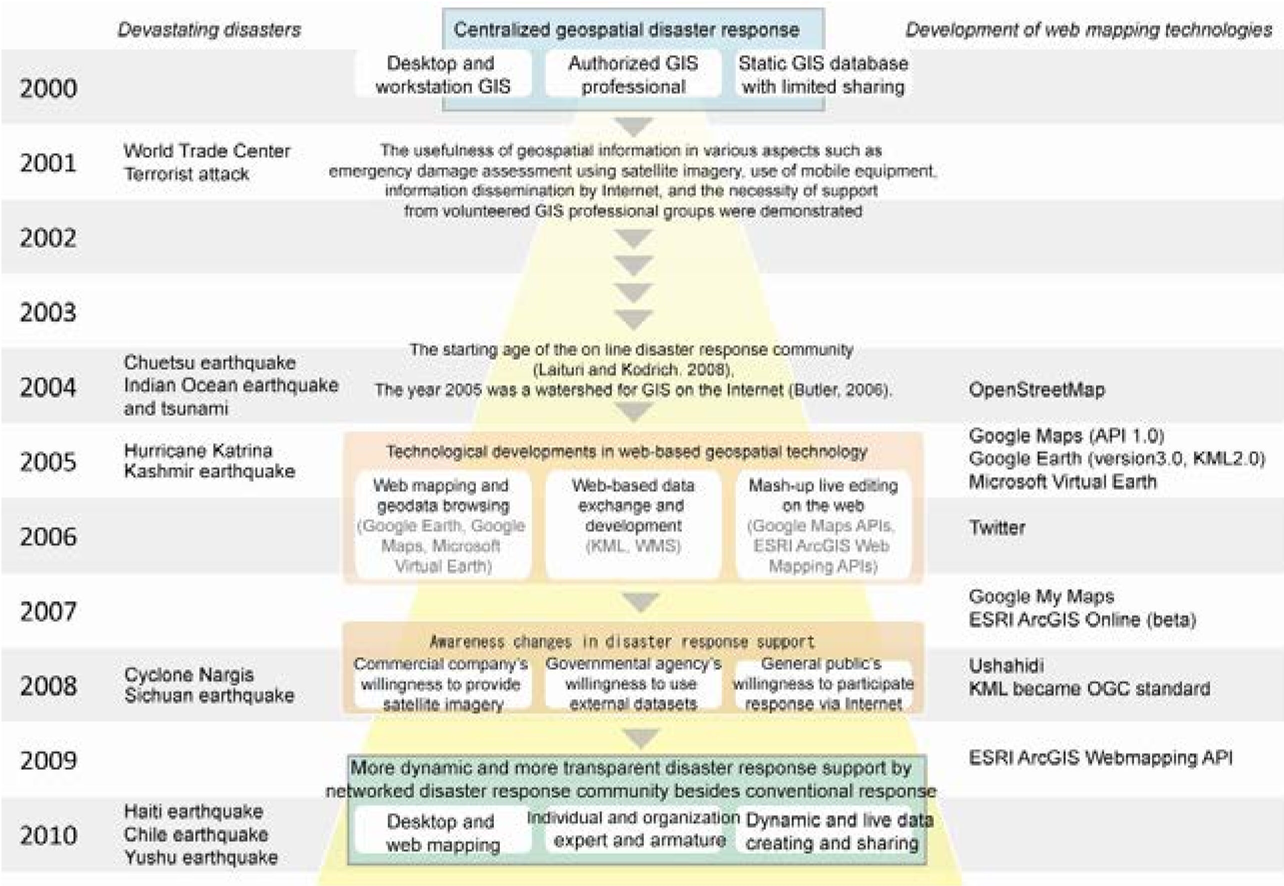

Figure 2: An overview of recent devastating disasters and the impact of changes in geospatial technology on disaster relief effort

4. LESSONS LEARNED AND SOME THOUGHTS FOR THE FUTURE

4.1 Power of crowd-sourcing

At the time of the Sichuan and Haiti earthquakes, organizations were responding separately and coordination among interested parties had by no means been solved. This led the Center for Geographic Analysis (CGA) to establish a geospatial portal, and through their experience CGA found that the sooner the portal starts, the more likely connections to the wider community would occur. The data had to be both portable for users to acquire and at the same time easy to browse online, and all of the content had to be freely available to everyone.

Historically, both data creation and mapping in support of disaster response required professionals skillful in GIS who also had access to a broad set of data for base mapping (Curtis et al., 2006, Radke et al., 2000, Zook et al., 2010). However, advanced GIS skills are no longer required to meaningfully contribute spatial data for disaster response. Oftentimes, GIS information that is needed for immediate emergency response is inherently simple, requiring not complex analytical procedures but rather reliable and adequate data (Laituri and Kodrich, 2008). Geographic information need only be good enough to assist recovery workers using the maps, meaning that crowd-sourced information is likely to be just as helpful as that produced by more centralized means. Given the need in disaster response for reliable maps the model of peer-produced mapping provides a number of new avenues for producing and accessing spatial data, besides the traditional top-down GIS provision models (Zook et al., 2010).

Perhaps the greatest benefit to this form of distributed mapping is in the greater quantity of geodata that can be produced and published in a shorter period of time, allowing scarce technical resources to be diverted elsewhere. This is oftentimes faster than government agencies (Laituri and Kodrich, 2008). Crowd-sourcing is about more than just volunteers and amateurs, however – it is about creating fluidity in data sharing and collaboration by breaking down barriers to technology and participation through the web, open standards, and simplified interfaces.

However, the rapid response and reliable data are only part of the picture of crowd-sourcing: we also need to consider how the crowd-sourced information was actually processed and vetted, then fed into the live mash-ups. We have to recognize this basic part of the infrastructures to understand why the Ushahidi team was so successful. Ushahidi set up a system of SMS and phone banks where volunteers received information in real time, which other teams of volunteers checked and evaluated as incoming streams of information, then approved items that would appear instantly on their website (Smith, 2010, Provencher, 2010). The data management process of a crowd-sourcing operation is the key element that determines the success or failure of this new data creation endeavor.

4.2 Need for disaster response plans which utilize networked disaster response community

Disaster communications used to be strictly top-down, hierarchical and linear, where public officials and experts were the ones who pushed the information out (Mills et al., 2009), but experience has shown that this approach to data sharing in disaster management is not entirely effective (Radke et al., 2000). Except for special cases such as Haiti, where the central government collapsed, a governmental agency or relief response organization should play a centralized role for coordinating general disaster response. Considering the scale and complexity of the problems presented by recent disasters it was evident that no stakeholder alone could tackle them, exposing the need for greater collaboration (Pezzoli et al., 2007). Therefore, government and relief response organizations have to understand how to harvest energy from this new movement in the web-based geospatial technological development and emergence of crowd-sourced responders. Crowd-sourced disaster response demonstrated the power and speed with which people could disseminate information (Laituri and Kodrich, 2008). It is important to have an established plan that includes this crowd-sourced movement in order to maximize the use of volunteers in the geospatial response and direct resources from all over the world (Zook et al., 2010, Curtis et al., 2006). In addition, collaboration and coordination between governmental agencies, relief organizations, and commercial companies remain problematic due to conflicting missions, data security issues, and inadequate funding of emergency response technologies (National Research Council, 2007, Laituri and Kodrich, 2008).

Understanding the capabilities of the crowd-sourced disaster responders offers an opportunity for integration of local perspectives and skills to augment agencies stretched to capacity by a devastating disaster and inadequate funding (Laituri and Kodrich, 2008).

At the same time, some effort needs to go into coordinating the crowd-sourced data streams (which can be collected and processed anywhere) with disseminating live information to the people on the ground (which can only be done on site and which usually has no power, no internet access, etc.). From an author's conversations with US Department of Health and Human Services staff and the first responder agencies, what was really missing was the ability to feed the updated info about the situation on the ground directly into the hands of the on-site responders. For example, Ushahidi did a brilliant work of getting OpenStreetMap coverage digitized for Port Au Prince and added tons of useful fresh information about road blockages, food and water distribution points, etc. However, those webmaps were not available to the responders on the ground. What was missing was just a clearinghouse at ground zero, like a phone bank or just a black board, where some kind of live updates could be kept track of, indicating which hospitals had open beds and what kind of surgeons or equipments on site. The responders just need to immediately get an injured person to the facility that was closest and had staff and capability of treating the casualty.
There are discussions whether governmental agencies should lead this role for information centralization or other entities in the distributed network should take this role (Rajabifard, 2006). Governmental agencies tend to hesitate in sharing data to external entities due to its organizational characteristics (Elwood, 2008, Harvey and Tulloch, 2006, Tombs, 2005), but creating barriers for collaborating with crowd-sourcing responders should be avoided. Even though a government agency needs to limit data sharing to some degree, they also have to maximize their limited sources by integrating external resources. Data sharing has to always remain highly available for the public.

4.3 Quick response vs. long-term strategy of geospatial database development

Zook (2010) suggested that detailed databases which used to take years to create now had to be accomplished in a matter of days using collaborative user environment such as OpenStreetMap. It is true that this kind of activities is useful for emergency response against disaster. At the same time, however, we wonder if these datasets can be utilized in long-term recovery planning and rebuild. Feature datasets created through OpenStreetMap are in a simple GIS format; this is not a well-structured spatial data model with modeling and analytical capabilities such as ESRI's geodatabase data model. It is a good opportunity to creating geospatial datasets after a devastating disaster, especially in developing countries. A new comprehensive geospatial database could be useful not only in emergency response but also in long-term national or regional planning, including addressing other issues such as climate change adaptation and global warming mitigation. The development of multifunctional databases allows a variety of applications such as revenue collection, natural resource protection, land-use planning, and infrastructure planning as well as disaster planning (Laituri and Kodrich, 2008, Montoya, 2003). Long-term strategy for building and utilizing such multifunctional geospatial database should be considered so that we do not waste the effort to create a variety of datasets which was intensively devoted to disaster response through humanitarian crowd-sourcing.

5. CONCLUSIONS

This paper examined how disaster response and relief efforts have been changing along with recent geospatial technological development through Haiti earthquake responses. This paper outlined how conventional GIS disaster responses by governmental agencies and relief response organizations and the means for geospatial data sharing have been innovatively transformed into a more dynamic, more transparent, and decentralized form with a wide range of participation.

Web mapping and geospatial data browsing with high-res satellite images and advanced data exchange and web mapping technologies have combined professional expertise and public involvement on a common geospatial platform. In addition to the conventional governmental approach, open source and voluntary activities are greatly expanding and developing. Coordination of interactive collaboration for using such crowd-sources and conventional professional response is essential for better response, but to achieve that an understanding of the trend in technologies is essential.

Geospatial technology is still rapidly expanding and growing. Looking towards the future, we hope to extend the overview of disaster events into topical sections devoted to particular fields of research, such as public health, civil engineering, economics, and more by tracking the lives of those displaced by the earthquake and by observing remediation efforts. We hope this paper shows such a perspective on the future.

REFERENCES

Butler, D. (2005). "Quake aid hampered by ban on web shots." Nature 437: 1072-1073.

Butler, D. (2005). "UN opens access to earthquake shots." Nature doi:10.1038/news051017-12.

Cova, T. J. (1999). GIS in emergency management. Geographic Information Systems: Principles, Techniques, Applications, and Management. P. A. Longley, M. F. Goodchild, D. J. Maguire and D. W. Rhind. New York, USA, John Wiley & Sons: 845-858.

Curtis, A., J. Mills, W., et al. (2006). Hurricane Katrina: GIS Response for a Major Metropolitan Area. Quick Response Report. 180: 1-6.

Cutter, S. L. (2003). "GI science, disaster, and emergency management." Transactions in GIS 7(4): 439-445.

Elwood, S. (2008). "Grassroots groups as stakeholders in spatial data infrastructures: challenges and opportunities for local data development and sharing." International Journal of Geographical Information Science 22(1): 71-90.

Gobierno de Chile Ministerio de Planificacion. (2010). "InfoPais." from http://www.infopais.cl/.
Google. (2006). "Google Earth and Katrina help." The Official Google Blog, from http://googleblog.blogspot.com/2006/07/google-earth-and-katrina-help.html.
Greene, R. W. (2002). Confronting Catastrophe: A GIS Handbook. Redlands, CA, ESRI Press.
Harvey, F. and D. Tulloch (2006). "Local-government data sharing: Evaluating the foundations of spatial data infrastructures." International Journal of Geographical Information Science 20(7): 743-768.
Householder, E. J. (1999). "Lifesaving choices: Developing a comprehensive critical facility geo-spatial database for regional emergency management." Proceedings of the 19th ESRI International User Conference: #445.
Huych, C. K. and B. J. Adams (2002). Emergency Response in the Wake of the World Trade Center Atttack: The Remote Sensing Perspective, Engineering and Organizational Issues Related to the World Trade Center Terrorist Attack. MCEER Special Report Series. 3.
ISDR (2009). Global Assessment Report on Disaster Risk Reduction. Geneva, Switzerland.
Johnson, G. O. (1992). "GIS application in emergency management." URISA Journal 4: 66-72.
Katayama, T. (1991). Earthquake damage assessment by considering local characteristics. Research and Survey on Earthquake Insurance. Tokyo, Japan. 30.
Kawasaki, A. and S. Sadohara (2005). "Investigation of the utilization of GIS in emergency response to the 2001 WTC building collapse disaster No.2: Through the interviews in New York City." Proceedings of the Annual Conference of Institute of Social Safety Science 16: 1-4.
Laituri, M. and K. Kodrich (2008). "On line disaster response community: People as sensors of high magnitude disasters using Internet GIS." Sensors 8: 3037-3055.
Matsuoka, M., Yamazaki, F. (2001). "Characteristics of satellite SAR intensity images in building damage areas due to the 1995 Hyogo-ken Nanbu Earthquake." Journal of Architecture and Structure 546: 55-61.
Matsuoka, M., Yamazaki, F., Midorikawa, S. (2001). "Characteristics of satellite optical images in areas Damaged by the 1995 Hyogo-ken Nanbu Earthquake." Journal of Structural Mechanics and Earthquake Engineering 668(I-54): 177-185.
Meguro, K., Soejima, M., Yamazaki, F., Katayama, T. (1999). "Classification of urban area by characteristics of power load curve." Information Technology Tools for Natural Disaster Risk Management- Proceedings of International Symposium: 263-274.
Mills, A., R. Chen, et al. (2009). "Web 2.0 emergency applications: How useful can Twitter be for emergency response?" Journal of Information Privacy & Security 5(3): 3-26.
Mitsutomi, H., Matsuoka, M., Yamazaki, F. (2002). "A study on a general automated detection method of building damage areas using aerial television images." Journal of Structural Mechanics and Earthquake Engineering 710(I-60): 413-425.
Montoya, L. (2003). "Geo-data acquisition through mobile GIS and digital video: an urban disaster management perspective." Environmental Modelling & Software 18: 869-876.

National Research Council (2007). Successful Response Starts with a Map: Improving Geospatial Support for Disaster Management. Washington, D.C., The National Academies.

Nourbakhsh, I., Sargent, R., Wright, A., Cramer, K., McClendon, B., Jones, M. (2006). "Mapping disaster zones." Nature 439(7078): 787-788.

OpenStreetMap. (2010). "WikiProject Haiti." from http://wiki.openstreetmap.org/wiki/WikiProject_Haiti.

Pezzoli, K., R. Tukey, et al. (2007). "The NIES environmental health sciences data resource portal: Placing advanced technologies in service to vulnerable communities." Environmental Health Perspectives 115(4): 564-571.

Provencher, K. (2010). "Crowdsourcing Crisis Response." from http://enews.tufts.edu/stories/1621/2010/02/05/crisismapping.

Radke, J., T. Cova, et al. (2000). "Application challenges for geographic information science: Implications for research, education, and policy for emergency preparedness and response." URISA Journal 12(2): 15-30.

Rajabifard, A., Binns, A., Masser, I., Williamson, I. (2006). "The role of sub-national government and the private sector in the future spatial data infrastructures." International Journal of Geographical Information Science 20(7): 727-741.

Rolbein, S. (2010). "Haiti Leaders, BU Team Share Long-Term Goals." BU Today In the World, from http://www.bu.edu/today/world/2010/01/24/haiti-leaders-bu-team-share-long-term-goals.

Saito, K., Numata, Y., Shimamura, H., Zhu, L., Akamatsu, Y., Nakayama, Y., Miyazaki, S. (2009). "Investigation report on the use of remote sensing technology in large-scale disaster assessment." Seisan-kenkyu 61(4): 157-163.

Sawada, M., Yagi, H., Hayashi, H. (2005). "A Study on the Technique for Information Sharing and Presentation of Earthquake Disasters : By the Chuetsu Earthquake Restoration and Revival Support GIS Project." Journal of Social Safety Sciences 7: 97-102.

Smith, J. F. (2010). "Tufts map steered action amid chaos." from http://www.boston.com/news/world/latinamerica/articles/2010/04/05/tufts_project_delivered_aid_to_quake_victims/.

Thomas, D. S. K., S. L. Cutter, et al. (2002). Use of spatial data and geographic technologies in response to the September 11 Terrorist Attack. Quick Response Report. 153.

Tombs, R. B. (2005). "Policy review: Blocking public geospatial data access is not only a homeland security risk." URISA Journal 16(2): 49-51.

Underwood, S. (2010). "Improving disaster management." Communications of the ACM 53(2): 18-20.

Yoshitomi, P. (2004). "The role of GIS in the response to the terrorist attacks of September 11 in New York City." Annuls of Disaster Prevention Research Institute, Kyoto University 47(C): 325-330.

Zook, M., M. Graham, et al. (2010). "Volunteered geographic information and crowdsourcing disaster relief: A case study of the Haitian Earthquake. World Medical & Health Policy. 2(2). DOI: 10.2202/1948-4682.1069.

Classification of Building Area using Slanted Angle and Density Indices Derived from Polarimetric SAR Data

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ABSTRACT

Urban extraction is one of the most expected applications using remote sensing, but the automatic extraction has been challenging. Especially in the field of synthetic aperture radar (SAR) applications, the complex scattering in the urban area is sensitive to the building spatial arrangement, and it prevents from the extraction. Spaceborne polarimetric synthetic aperture radar (POLSAR), an advanced approach to SAR, has been operated since ALOS/PALSAR was launched in 2006. Several indicators derived from POLSAR data have been developed to classify landcovers, and some of them have been utilized to extract the geometric features of the target. So as a first step, we measured the backscattering from the concrete blocks arranged in different slanted angles and distances in an anechoic radio wave chamber. In this experiment, it was found the interrelation between spatial arrangement and such polarimetric indices. As a result, it is demonstrated that Polarization Orientation Angle (POA) is a good detector for slanted angle of man-made structures, and of all the indicators, entropy has the highest correlation with building density. Then, using satellite polarimetric data, we discriminated urban areas according to the classifier using POA and entropy. The comparison with aerial photo indicated that POA is an effective indicator to extract the slanted buildings and that there are some areas where entropy distinguishes the difference of building density.

Keywords: *urban extraction, POLSAR, POA (Polarization Orientation Angle), entropy*

1. INTRODUCTION

From the viewpoint of city planning or disaster prevention, spatial arrangement and structures of buildings in urban areas are important data. While accurate measurement of such urban features using terrestrial sensors such as LiDAR (Light Detection and Ranging) is quite costly, the airborne or spaceborne sensors are expected to measure the widespread data at a relatively low-cost. Especially synthetic aperture radar (SAR) is highly expected for immediate observation after disasters and so on, for it is available even at night or in bad weather. However, accurate urban monitoring by SAR has been difficult so far, because the result is seriously affected by relative slanted angle of measured buildings to observation direction.

Polarimetric synthetic aperture radar (POLSAR), an advanced approach to SAR is reported to detect various information of land surface which cannot be acquired by optical sensor. Several indicators derived from POLSAR data have been developed, and some of them have been utilized to extract the geometric features of the target. One of such indicators is Polarization Orientation Angle (POA), which is reported to estimate slanted angle of the target (Kimura *et al*., 2005). In addition, the indicators related to the density of the target are also proposed. Utilizing these indices in urban area, reliability of monitoring could be better.

Therefore, the objective of this research is to improve the accuracy of extraction of urban area from POLSAR data, and we aim at the method which is independent of slanted angle and can detect spatial arrangement (density, height) of the buildings.

2. USED INDICES

POLSAR data has the complex scattering matrix given by

$$S = \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} = \begin{pmatrix} a & c \\ c & b \end{pmatrix} \tag{1}$$

assuming that S_{hv} and S_{vh} are equivalent. The indices shown in this section are derived from this scattering matrix. Further, some indices utilize the coherency matrix represented by

$$T = \begin{pmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix} = \begin{pmatrix} |a+b|^2 & (a+b)(a-b)^* & 2(a+b)c^* \\ (a-b)(a+b)^* & |a-b|^2 & 2(a-b)c^* \\ 2c(a+b)^* & 2c(a-b)^* & 4|c|^2 \end{pmatrix} \tag{2}$$

2.1 Polarization Orientation Angle (POA)

Polarization Orientation Angle θ compensates scattering matrix as follows

$$S(\theta) = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} a & c \\ c & b \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \tag{3}$$

θ is determined so that the target would stand perpendicular to the orbit

$$\theta = \frac{1}{4}\tan^{-1}\left(\frac{4\,\mathrm{Re}(|a-b|c^*)}{|a-b|^2 - 4|c^*|^2} \right) \qquad \left(-\frac{\pi}{4} \le \theta \le \frac{\pi}{4} \right) \tag{4}$$

This is the same as the minimization of T_{33} element of coherency matrix, and POA is equal to the phase term of circular polarization coefficient. POA is reported to estimate slanted angle of the target.

2.2 Entropy (Cloude and Pottier, 1997)

Coherency matrix can be diagonalized using unitary matrix U as follows

$$T = \begin{pmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix} = U \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{pmatrix} U^* \tag{5}$$

where λ_1, λ_2 and λ_3 are the eigenvalue of the matrix T. Entropy H is given by

$$H = -\sum_{i=1}^{3} P_i \log_3 P_i \tag{6}$$

where

$$P_i = \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \qquad (i = 1,2,3) \tag{7}$$

Entropy shows the randomness of scattering. Only surface scattering would occur in H=0, while various scattering (e.g. surface scattering, volume scattering, double bounce scattering) would randomly occur in H=1. Entropy is often used in land cover classification.

2.3 Four-Component Decomposition (Yamaguchi *et al.*, 2005)

Four-component decomposition has been developed from three-component decomposition (Freeman and Durban, 1998). In this method, measured polarimetric scattering wave is decomposed into scattering components based on physical scattering process: surface scattering (Ps), volume scattering (Pv), double bounce scattering (Pd), and helix scattering (Pc). Scattering matrix is decomposed into the summation of the basic scattering matrices of the four components, and then coefficients of the four matrices are calculated, which determines the power of each component.

2.4 Target Decomposition Method (Dong *et al.*, 1998)

Dong et al. proposed another decomposition model that is fit for urban structures. The components derived after decomposition are double bounce scattering (DB), odd bounce scattering (OB), bragg scattering (BS), and cross-polarized scattering (CS).

3. ANALYSIS OF X-BAND EXPERIMENTAL DATA

3.1 Experiment

On September 8 and 29, 2009, we carried out an experiment in the anechoic radio wave chamber in Wave Engineering laboratory, Department of Information Engineering, Faculty of Engineering, Niigata University. One of the purposes is to examine whether POA is sensitive to slanted angle of man-made targets, the other is to judge which index has the strong correlation with density of them. Used radar system and object are explained below.

3.1.1 Radar System

The polarimetric measurement system which is capable of synthetic aperture process was used. Figure 1 shows the radar and the zoom of its antennas. Each of the four antennas corresponds to horizontal polarization transmit, horizontal polarization receive, vertical polarization transmit, and vertical polarization receive. The wave frequency is X-band (10 GHz), the antenna height is 180 cm, and the incident angle is 45°.

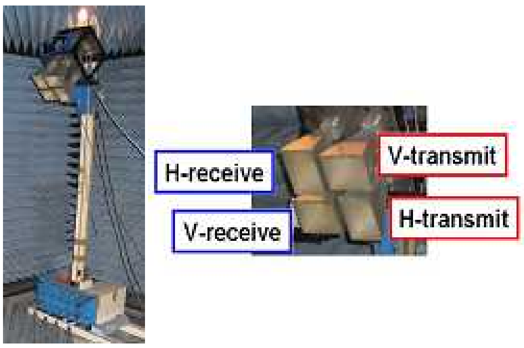

Figure 1. (Left) Radar system for the experiment. (Right) Zoom of its antennas.

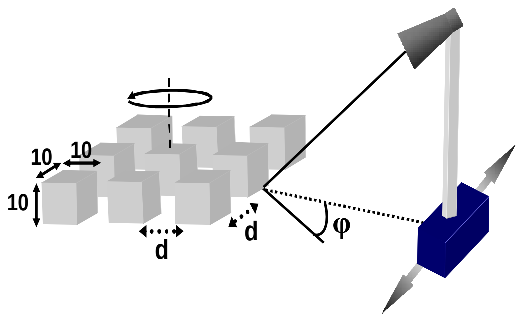

Figure 2. Schematic diagram of the measured structure. d is the distance of the blocks (three distances), φ is the slanted angle of the blocks (six angles).

3.1.2 Object to Measure

Nine concrete block cubes were arranged to measure and analyze the backscattering. The cube has 10-cm length, and the arrangement of the blocks is displayed in Figure 2. As illustrated in the figure, blocks were placed on 3×3 grid. The slanted angle of the structure was defined as 0° when the sides of the blocks are perpendicular to the radar path. First, the structure was measured at 0°, then the whole structure was rotated right-handedly in steps of 15°. Following the same procedure, the data at six slanted angles were measured. Moreover, at each slanted angle, the structure was measured three times with the distance of blocks 10 cm, 15 cm, and 20 cm, i.e., the measurement was done eighteen times in total.

3.2 Results and Discussion

From the data acquired in the experiment, each index described in the previous section was calculated.

The left graph of Figure 3 shows the relationship between POA and the slanted angle of the blocks. It was found that POA and actual slanted angle have linear relationship when slanted angle is set between 15° and 75°. Moreover, in the analysis using four-component decomposition (Iwasa *et al.*, 2009), it is proved that Ps and Pd become greater if buildings are perpendicular to the radar path (the result is shown in the right graph of Figure 3); thus slanted angle of the building may be estimated using four-components together with POA.

Next, Figure 4 demonstrates the relationship between entropy and the distance of the blocks. Entropy increases in all slanted angles when the distance changes from 10 cm to 15 cm, while it decreases in almost all the slanted angles when the distance changes from 15 cm to 20 cm. Therefore, entropy and building density may have nonlinear relationship. Furthermore, the relationship between four-components and the distance of the blocks is shown in Figure 5. As seen in figures, no component has better correlation with the distance than entropy. Target Decomposition Method was also investigated, and it was found that it did not show good relationship with the distance of the blocks, either.

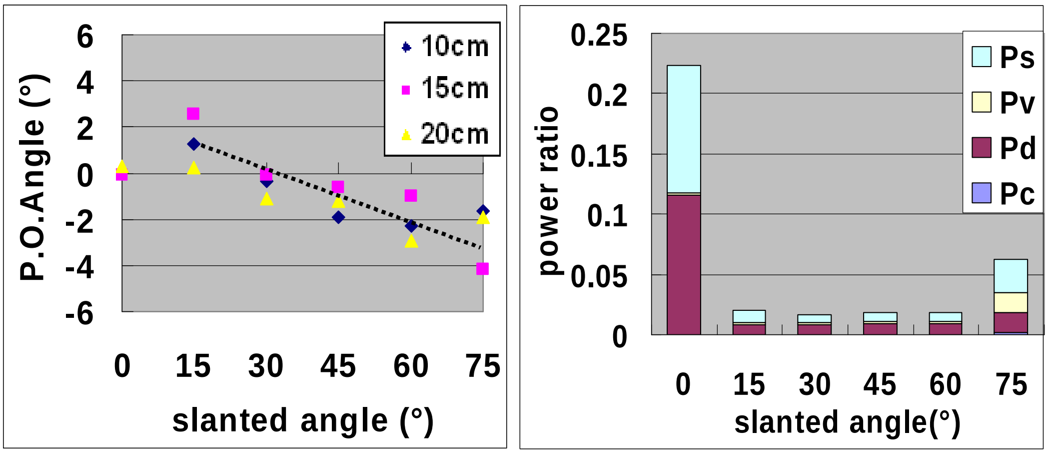

Figure 3. (Left) Relationship between POA and the slanted angle of the blocks. (Right) Relationship between four-components and the slanted angle of the blocks. Power ratio in the vertical axis means the ratio to the total power acquired in the measurement of a conductor sphere. In this case, the distance of the blocks is 20 cm. The result was very similar when the distance is 10 cm or 15 cm.

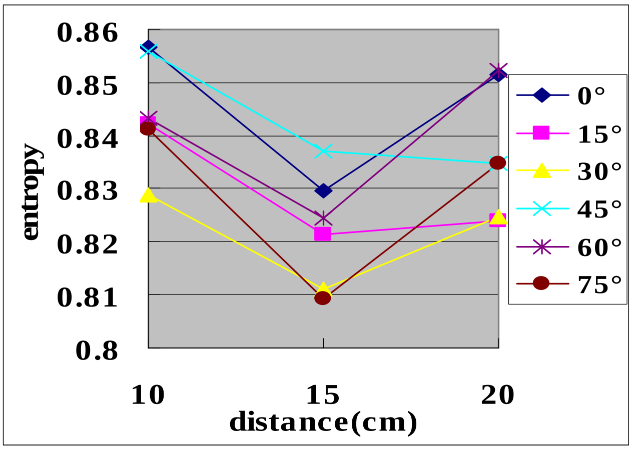

Figure 4. Relationship between entropy and the distance of the blocks.

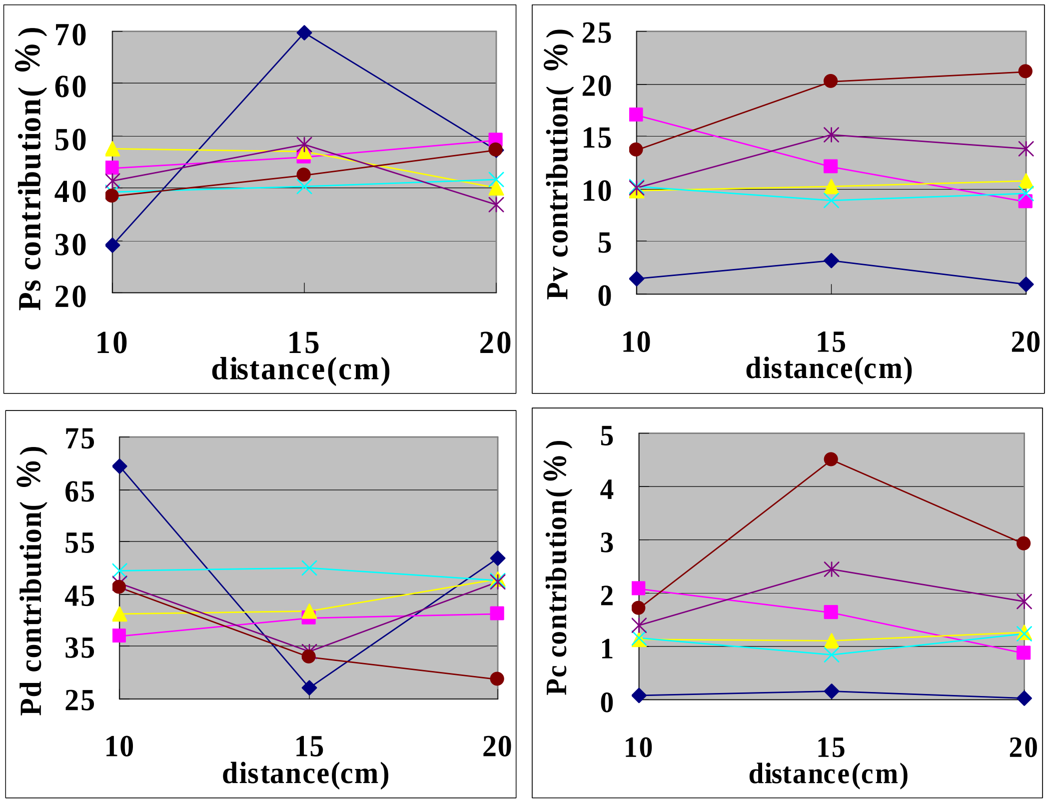

Figure 5. Relationship between four-components and the distance of the blocks. (Upper left) surface scattering. (Upper right) volume scattering. (Lower left) double bounce scattering. (Lower right) helix scattering

4. APPLICATION TO L-BAND POLSAR FOR BUILDING CLASSIFICATION

In the experiment described in the previous section, two indices turned out to be available for the estimation of urban structural quantities; POA is for slanted angle, and entropy is for density. In this section, to discriminate urban areas extracted from ALOS (Advanced Land Observing Satellite) / PALSAR (Phased Array type L-band Synthetic Aperture Radar) polarimetric images, a decision-tree classifier is proposed, which utilized the two indices. In addition to ALOS/PALSAR data, ALOS/ AVNIR-2 (Advanced Visible and Near Infrared Radiometer type 2), one of the optical sensors, is utilized to divide urban area and non-urban area.

4.1 Data

The 1.1 level PALSAR data provided by JAXA was analyzed. Level 1.1 is the range- and azimuth-compressed complex data (single look complex: SLC). It contains latitude-longitude information in a slanted-range coordinate. Phase and amplitude of the scattered wave can be calculated from the image. ALOS/AVNIR-2 data, which is used together with ALOS/PALSAR, is composed of 4 bands belonging to visible or near infrared bandwidth.

4.2 Classification Algorithm

Figure 6 shows the classification algorithm using POA and entropy. Each step of the classification is explained below.

4.2.1 Urban Area Extraction from Optical Data

Using optical data, it is relatively easy to divide urban area and non-urban area. In this step, all pixels are classified with Maximum Likelihood Method into five or six landcovers; “urban”, “farmland”, “forest”, “water”, etc. Then the classes except for “urban” are merged, and removed as non-urban area.

4.2.2 Non-Building Area Removal using Total Power

Compared with building area, non-building (flat) area generally has lower Total Power (*TP*), the summation of the elements of scattering matrix. Therefore, pixels which have lower *TP* value than certain threshold are extracted as non-building.

4.2.3 Perpendicular Building Extraction using Four-Component

In the previous research (Iwasa *et al.*, 2009), it is ensured that the buildings perpendicular to the radar path are detectable using four-component decomposition. Based on this, pixels which have higher Ps and Pd value than certain thresholds are extracted as perpendicular building.

4.2.4 Segmentation using POA

Remaining pixels, which are regarded as slanted buildings, are divided using θ value into several categories. Before the segmentation, θ value is averaged with 7×7 filtering window. The segmentation is done so that each category approximately contains the same number of pixels.

4.2.5 Segmentation using Entropy

All building categories (including perpendicular buildings extracted at 4.2.3) are divided using H value into several clusters. Before the segmentation, H value is averaged with 7×7 filtering window. The segmentation is done so that each cluster approximately contains the same number of pixels. After the segmentation, isolated pixels, whose all adjacent pixels are in other clusters, are reclassified.

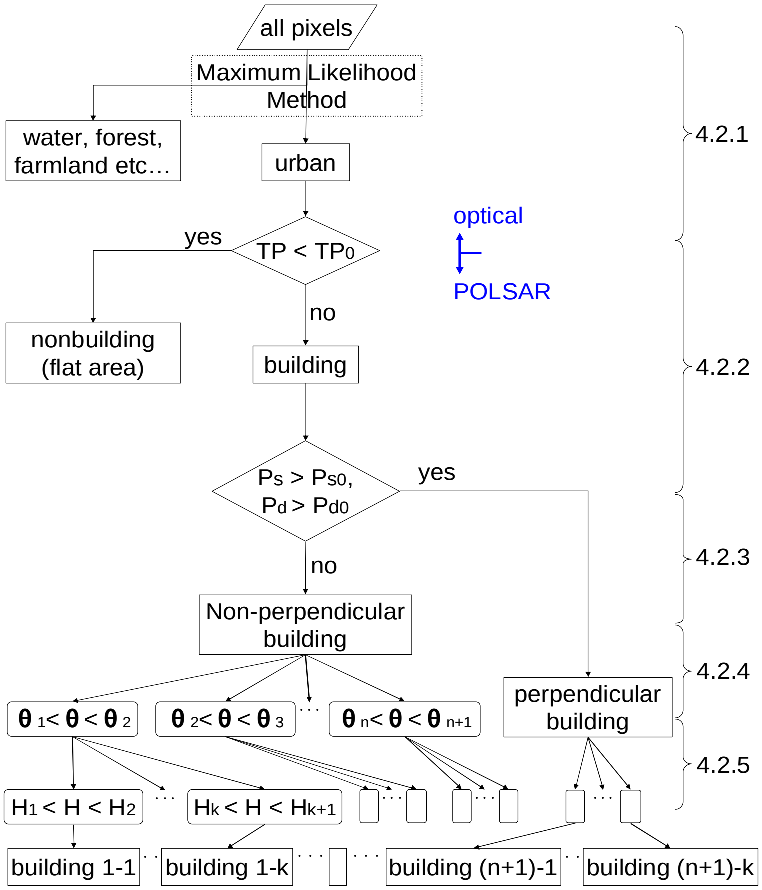

Figure 6. Building classification algorithm.

4.3 Results and Discussion

In the algorithm above, the number of the categories generated using POA is set to 5, and the number of the clusters generated using entropy is set to 10.

First, the data of coastal region in Urayasu city, Japan, is analyzed (Region 1). PALSAR and AVNIR-2 data was observed on July 17, 2006 and August 4, 2006, respectively. In Figure 7, classification result is compared with aerial photograph of the same region. In image (B), buildings are extracted from aerial photograph and colored according to their slanted angle. From the classification result (C), it can be seen that the center and right part of the image are classified into blue area, while the left part is into light blue area. Similarly, aerial photograph shows that these two parts have different trend in slanted angle of buildings.

Second, the data of plain region around Kyoto city, Japan, is analyzed (Region 2). PALSAR and AVNIR-2 data was obtained on June 2, 2007 and May 15, 2008, respectively. Figure 8 exhibits classification result and aerial photograph of the same region. From the classification result (C), it can be seen that the right side of the image is classified into purple, perpendicular area, while the left side is mainly into blue area. Correspondingly, it is found from aerial photograph that this division roughly follows the distribution of the actual slanted angle of the buildings. Consequently, segmentation of buildings according to their slanted angle can be clearly done using POA and four-component decomposition.

Moreover, the lower left part of image (C) is classified into high entropy area. Considering that relatively small buildings are densely distributed in the same part of aerial photograph, entropy seems to be working well to detect the change of spatial distribution in this region.

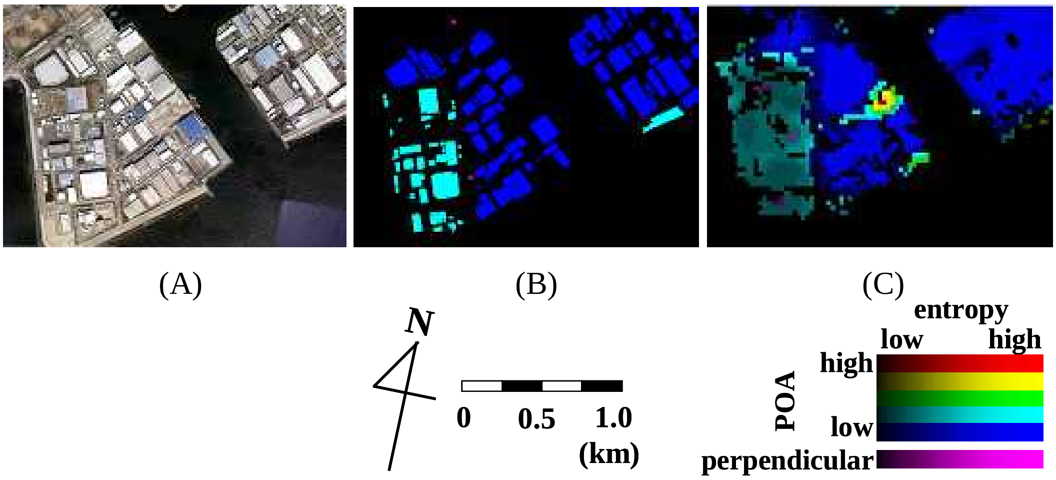

Figure 7. Classification result in Region 1 (A) Aerial photograph from Google Earth. (B) Extracted buildings from photograph (A). (C) Classification result using the proposed decision-tree classifier. POA value corresponds to the rainbow color, and tone of each color differs according to entropy value.

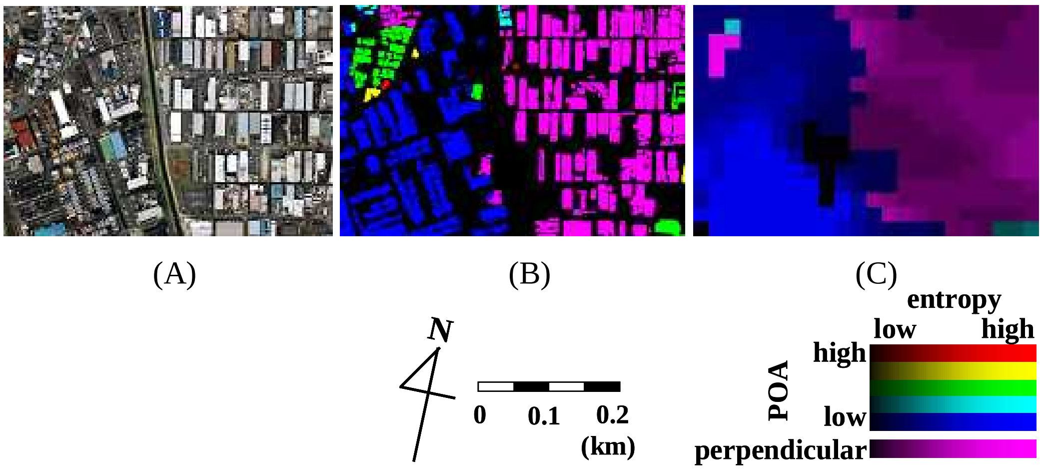

Figure 8. Classification result in Region 2. (A) Aerial photograph from Google Earth. (B) Extracted buildings from photograph (A). (C) Classification result using the proposed decision-tree classifier. POA value corresponds to the rainbow color, and tone of each color differs according to entropy value.

5. CONCLUSIONS

In this research, we examined the effectiveness of polarimetric indices as urban structural detectors through the analysis of laboratory experiment data, and we also applied some of the indices to ALOS/PALSAR data according to the decision-tree classifier based on the experimental results.

The experimental results demonstrated that POA has linear relationship with building slanted angle. Also, it confirmed that entropy has the highest correlation with building density.

Through the analysis of satellite images, POA proved to classify buildings which are not perpendicular to the radar path according to their slanted angle. In addition, we found that there are some areas where entropy distinguishes the difference of building density. Considering these results, the algorithm using polarimetric indices applied in this research seems effective for the classification of urban area. Furthermore, in the beginning of the proposed algorithm, optical data is also used to separate urban area from natural areas. As less affected by factors of topography and terrestrial objects, classification results become more robust.

One of the future works is further improvement of classifier for POLSAR processing. In our analysis, the classifier may cause classification results to be unstable, especially when homogeneous areas with similar slanted angle of the buildings are relatively small. In addition, it is difficult to remove all the flat area using single threshold only. Therefore, refinement in both pre-classification and post-classification is needed. Besides, this kind of approach is expected to be applied immediately after disaster, e.g., detection of the area damaged by earthquake or tsunami. Thus, a case study in actually devastated area is desirable.

REFERENCES

Cloude, S. R., and Pottier, E., 1997. An entropy based classification scheme for land applications of polarimetric SAR, *IEEE Transactions on Geoscience and Remote Sensing*, 35, 68–78.

Dong, Y., Forser, B. C., and Ticehurst, C., 1998. A new decomposition of radar polarization signatures, *IEEE Transactions on Geoscience and Remote Sensing*, 36(3), 933-939.

Freeman, A., and Durden, S. L., 1998. A three-component scattering model for polarimetric SAR data, *IEEE Transactions on Geoscience and Remote Sensing*, 36(3), 963-973.

Iwasa, S., Susaki, J., and Tamura, M., 2009. Development of urban model using polarimetric synthetic aperture radar, *JSPRS Annual Conference*, 15-18, In Japanese.

Kimura, H., Papathanassiou, K.P., and Hajnsek, I., 2005. Polarization orientation effects in urban areas on SAR data, *Proceedings of the 2005 International Geoscience and Remote Sensing*, 4863-4867.

Uchida, N., Uchiyama, K., Yamaguchi, Y., and Yamada, H., 2009. A study on detection of urban area using Polarization Orientation Angle, *IEICE Technical Report*, 109(181), SANE2009-59, 37-42, In Japanese.

Yamaguchi, Y., Moriyama, T., Ishido, M., and Yamada, H., 2005. Four-component scattering model for polarimetric SAR image decomposition, *IEEE Transactions on Geoscience and Remote Sensing*, 43(8), 1699-1706.

Yamaguchi, Y., 2007. Radar Polarimetry from Basics to Applications, *IEICE*, 101-151.

Comparative Study of Satellite Remote Sensing Systems for Earthquake Disaster Mitigation

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ABSTRACT

A lot of earthquakes occur all over the world everyday and big earthquakes were reported in last few years, ex. in Sichuan (China), Java (Indonesia), Port-au-Prince (Haiti), and Concepcion (Chile). These earthquakes severely damaged infrastructures and human beings. Quick and appropriate information is required for mitigating the damages and recovering from the devastated condition. Therefore, the International Charter has been established to provide a unified system of space data acquisition and delivery to those affected by natural disaster. Each member agency has committed resources to support the provision of the Charter and thus is helping to mitigate the effects of disasters on human life and property. The damaged countries can freely use its satellite data but their appropriateness is not clear. This study made up a decision rule to select the appropriate data from the Disaster Charter according to the characteristics of spatial and time resolution as well as spectral characteristic. We took into account the observation cycle time, the geometrical parameters of observation data and land cover types of damaged area.

Keywords: Satellite remote sensing, earthquake, Disaster Charter

1. INTRODUCTION

The use of remote sensing technology had been widespread for monitoring the earth. One of the reasons for that is satellite's performance became better than past. The new satellites have high resolution and/or high performance sensor, for example IKONOS which is used from September in 1999, has resolution of 1.0m and QuickBird which is used from October 2001, has that of 0.61m. These are NASA's Earth Observe (EO) Satellite. As for Japanese EO Satellite, ALOS's PRISM which is used from September 2005 has that of 2.5m. Thanks to that capacity to provide a lot of information about earth's global coverage and the specific area, using satellite data enabled us to monitor pre- and post- disaster's damage caused by disaster. And about the mitigation of the disaster, using satellite data is valid because a lot of (more than 3000) Earth Observe (EO) Satellites are available. Though one satellite's cycle time is very long, for example ALOS's cycle is 46days, it enabled us to monitor the earth in short cycle time by utilizing a lot of EO satellites which is total numbers of EO Satellites. But in fact, utilizing more than all 3000 satellite data is not realistic. Therefore utilizing each country's main satellite imageries is valid and enough for example IKONOS, QuickBird, ALOS, SPOT.

Monitoring the disaster needs to select and use satellite data. Each Satellite data has strength and limitation as high resolution imageries don't have wide observation width. That is because the satellite which has wide observation width is in high altitude; therefore that satellite has low resolution compared with that in low altitude. Satellite's resolution and observation width have trade-off relationship. Because natural disasters occur suddenly and cause unpredictable damage, it is necessary for us to use each satellite so that the merit of which is taken. It is necessary to decide which Satellite data we should use as the situation demands. Though satellite imagery for disaster management is widely used by the country where Space Agency exist and good-neighbor country with that country, the opportunity to use Satellite to the countries which don't have satellite restricted to the small part of the world. Then International Disaster Charter system was initiated by ESA and CNES to unify the world's satellite trade system. This system established effective mechanism in the way that joining members trade not raw data but analyzed information and with no funds being exchanged among them. International Disaster Charter is the only system to unify satellite systems of all over the world although there are some systems to unify the specific area like Sentinel Asia and Disaster Monitoring Constellation.

Picking up International Disaster Charter system helps us to understand current reality about Disaster Management by using satellite data in the world. This paper focuses on the current reality and what has been achieved thorough IDC activity.

In this study, analyzing the earthquake is the main theme because about 20% of the total number of earthquake occurred in Japan and mitigating the earthquake is significant problem in Japan. Therefore analyzing the earthquake disaster is very useful to mitigate disaster damage in Japan and eventually in Asia in the future.

2. International Disaster Charter (IDC)

2.1 About the International Disaster Charter (IDC)

ESA (European Space Agency, Europe) and CNES (Centre National d'Etudes Spatiales, French) set up and initiated the International Disaster Charter (IDC) following the Third United Nations Conference on the Exploration and Peaceful Use of Outer Space (UNISPACEⅢ)in 1999. In the UNISPACEⅢ,using space science and technology for solving common problems of regional or global significance was discussed with searching international coordination and using space technology of remote sensing in developing countries. IDC was established to pursue such objective along mitigating natural or man-made disasters. The ESA and CNES initiated the International Charter "Space and Major Disasters", with the Canadian Space Agency (CSA) signing the Charter on 20 October 2000. Now IDC induct 9 Space Agencies –ESA and CSA from 2000, NOAA (National Oceanographic and Atmospheric Administration, USA)/USGS (United States Geological Survey, USA), ISRO (Indian Space Research Organization, India) became the member of IDC in 2001, CONAE (Comission Nacional de Actividades Espaciales, Argentina) in 2003, BNSC (British National Space Centre, UK) and JAXA (Japan Aerospace Exploration Agency, Japan) in 2005 and CNSA

(China National Space Administration, China) in 2007. IDC aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property. The unique point of the charter is to provide satellite image and analyzed data free of charge to affected areas or countries, once the charter activation was set in motion. It is very helpful especially to developing countries which don't have satellite because they cannot afford to buy the satellite imageries and cannot understand what the satellite imagery and data means watching about satellite imagery. Each Space Agency member makes a contribution to open to the public and analyze the each satellite data. All charge of each Charter activity cost the Space Agency which organizes the Charter Project Manager which observes, obtains and analyzes the satellite data. For these reasons, the afflicted countries or area can obtain the satellite image and data free of charge.

2.2 Mechanism to activate the Charter

If heavy disaster occurs, the officers in the afflicted area first make contact with assigned AU (Authorized User). AU are civil protection, rescue, defense and security bodies of the country to which the participating Agencies belong. AU are recognized to be the Charter associated Bodies. Then main unit of the Charter office receive notification from AU and assign a Project Manager (PM). Here main body of the Charter includes ODO (On-Duty Operator) and ECO (Emergency on Call Officer). ODO Receives calls requesting space data imageries and information, Obtains and confirms with the AU when the information required. ECO processes the information which is received from ODO, identifies the timeliest and appropriate satellite resource, prepares a draft plan and gets the Space Agency user's approval. In the Charter, Project Manager takes all responsibilities for obtaining satellite images, analyzing the satellite data and distributing to End User.

In this Charter Operational Loop, afflicted Nations need contact with not directly the Space Agency but by way of a lot of mediations. This is because considering about developing countries which cannot analyze, understand and recognize the image data. Then Charter set up the mechanism which the main body decides which satellite data is suited for and distributes the analyzed data.

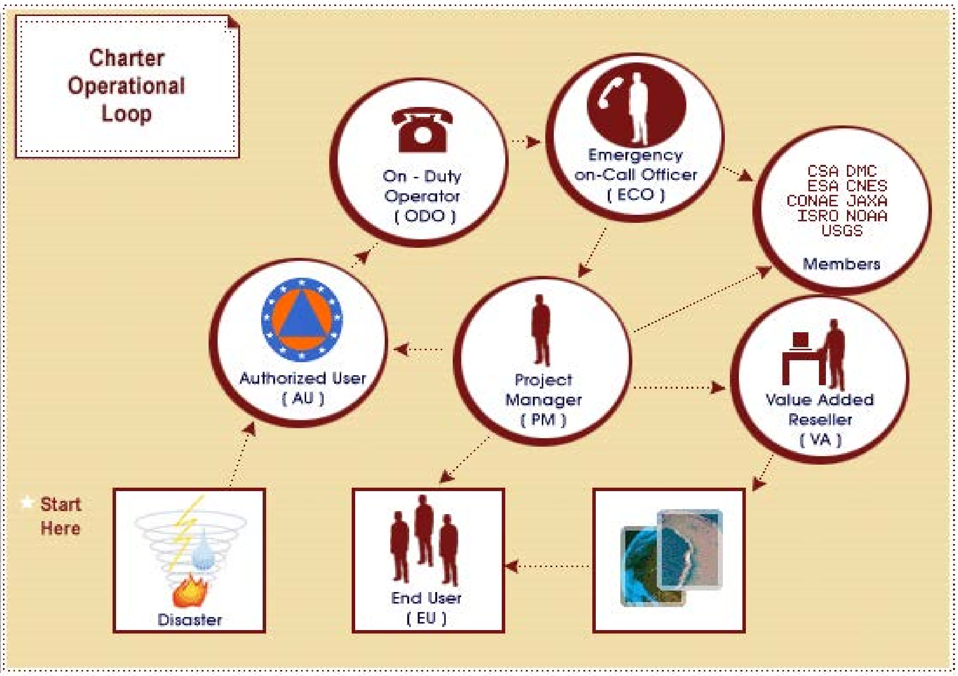

Figure1: Charter Operational Loop

3. About the Charter Activation

Although IDC accomplished good results in disaster management by using satellite, simultaneously there are some shortcomings. In this section, here are some shortcomings which need to be discussed.

3.1 Insufficient information

There are a lot of problems about insufficient problem. In the case of Earthquake and landslide in Costa Rica on 8th of January 2009, there are 8 satellite images of afflicted area. But all are described no information of Lat-Lon data and diminishing scale. This disaster occurred especially in mountains and it caused landslides. Many rural towns had been under serious landslide threat. Electrical infrastructure and roads were also seriously damaged. Especially for landslide disaster or disaster which occurred in mountains, Lat-Lon data and diminishing scale needs to attach because almost all the people go there to rescue and determine the extent of the damage where they hardly know and cannot understand what the image means.

3.2 No activation image

Simultaneously there are the problems about no activation occurred in charter activation. Although once charter was activated, no one answered and no satellite image was delivered. In case of earthquake disaster, 10 of 36 disasters correspond to this problem. All these 10 activations were activated in developing countries. For developing countries which don’t have satellite, there is no other way to get satellite data without IDC’s approach. Because developing countries need to be delivered satellite images and data and this is an objective of IDC, this problem must be discussed.

3.3 Response Time

According to the IDC's 2008 Annual Report, Response Time of the Charter activation is very close to 2 days in average. This time is faster than past days: that in 2003 is 2.5days according to 2003 Annual Report. But this is not sufficient because faster response time is required in disaster area. According to the information of Government of Japan, getting imageries 8times in one day is enough to monitor the earth using satellite in disaster management. And there is little information in afflicted area. Because ground is heavily damaged little information is delivered by way of ground. Only way to obtain information is using remote sensing technique. For these reasons satellite data by using remote sensing technique is so valid.
The problem of the late delivery is also necessary to be discussed. In case of Earthquake of Turkey occurred on 1st of May 2003, date of Activation is 8th of May and data delivered time of data is 8th of May or later than 8th due to no ftp transfer's problem. The problem is no ftp access in remote areas interferes in data delivery. Like this instance, some nations or areas don't have well operating infrastructure. For disaster management, the internet is the fastest and valid way. But developing countries may not possess enough infrastructures to meet their demands. For these reasons, considering developing countries, building infrastructure may be crucial for disaster management.

3.4 Coverage of the IDC

In disaster management, there is 4 stages in disaster management; preparedness, mitigation, response and recovery. IDC is intended for only mitigation, response and recovery then preparedness is not intended for. So for example in case of volcano eruption, IDC does not intend for it though volcano eruptions need to monitor before eruption occurred. It is necessary to broaden the IDC activation's coverage. As the comprehensive disaster management, it is necessary to cover all stages, pre- and post- disaster so that IDC will become more useful framework.

4. Conclusion and Discussion

IDC is the only worldwide international association for disasters using remote sensing technique. In their works, IDC met objectives and achieved the accomplishments below as the international association.

- IDC makes mechanism to exchange each state's satellite images and analyzed data and is helpful for developing countries because they don't have satellite data, data analyzing skill and engineering.
- IDC made mechanism all free of charge although satellite image and satellite data is commonly charge for obtaining and analyzing.
- Although each association made a role of satellite monitoring unsynchronized before IDC set up, IDC unified each Disaster Management Constellation and each Space Agency.

Although IDC made great accomplishment, simultaneously IDC needs to be discussed to become better association.

- There is no rule about satellite data's information and politics which should be delivered. Then satellite information is unsynchronized by each Space Agency.
- Although a lot of association and Space Agency belong to IDC, there is no rule on satellite data's information and politics. So it spreads responsibility so widely that each association's accountability is blurred.
- Afflicted areas or nations cannot access the satellite data and obtain the exact kind of data when they want to get it.

5. Future Works

Interviews to the officers associated with IDC are necessary to make it clearer IDC's current condition. Interviewing to them is taken into consideration in near future.

Table 1: Earth Observation Satellite Chart

	Satellite	Sensor	Resolution	Observation Width	Altitude	Cycle Time	Operated from
JPN	ALOS	PRISM	2.5m	70km,35km	692km	46	2005.9-
		AVNIR-2	10m	70km			
		PALSAR	10m	70km			
			100m	250-350km			
USA	LANDSAT-5	MSS	80m	185km	705km	16	1972.1-
		TM	30m				
	LANDSAT-7	ETM+	30m,60m,15m	185km	705km	16	1999.4-
	TERRA	MODIS	250m-1000m	2330km	705km	16	1992.12-
	IKONOS	Pancromatic	1.0m	11km	680km	11	1999.9-
		multi-spectral	4.0m				
	QuickBird	Panchromatic	0.61m	16.5km	450m	1-3.5	2001.10-
		multi-spectral	2.44m				
FRN	SPOT-4	HRVIR	20m(Multi)	60km	832km	26	1986.5-
			10m(Pan)				
		VGT	1.15km	2250km			
	SPOT-5	HRG	10m(Multi)	60km	832km	26	2002.5-
			5m,2.5m(Pan)				
		HRS	10m	120km			
		VGT	1.15km	2250km			
Europe	ENVISAT	ASAR	30m-1200m	100km-640km	800km	35	2002.2-
		MERIS	300m-1200m	1450km			
India	IRS-1C 1D	PAN	5.8m	70km	817km	24	1995.12-
	IRS-P6	PAN	5.8m	70km	817km	24	2003.10-
		LISS-III	23.5m	140km			
		LISS-Ⅳ	5.8m	23km			
		AwiFS	60m	740km			
	IRS-P5	HR PAN	2.5m	30km	617km	22	2005.5-
Canada	RADARSAT-1	FINE-ScanSAR	10m-100m	50km-500km	798km	24	1995.11-

REFERENCES

J.-L.Bessis, J.Bequignon, A.Mahmood, 2003, The International Charter 'Space and Major Disasters' initiative, Acta Astronautica 54, 183-190

J.-L.Bessis, Use of the International Charter Space and Major Disasters for Damage Assessment,

J.-L.Bessis, J.Bequignon, A.Mahmood, 2004, Three Typical Examples of Activation of the International Charter 'Space and Major Disasters' Advances in Space Research, 33, 244-248

International Disaster Charter, Executive Secretariat annual reports, No.1-No.8

International Charter 'Space and Major Disasters' Website: www.disasterscharter.org

Application of Satellite SAR Based Damage Detection Technique to the 2004 Niigata-ken Chuuetsu Earthquake and Its Upgrade, Japan Architecture Structure Association, 1-8

Data Book on Asia Natural Disasters in the 20th Century; www.adrc.asia/hilights/Newsno007.pdf

RESTEC Website; http://www.restec.or.jp/databook/index.html

USGS website; http://earthquake.usgs.gov/earthquakes/world/historical.php/

Ministry of Education, Culture, Sports, Science, and Technology, JAPAN Website (all sentences are in Japanese); http://www.mext.go.jp/b_menu/shingi/chosa/kaihatu/004/toushin/06103014/001.htm

Automatic co-registration of SAR images and close-range photographs using SIFT

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ABSTRACT

This paper presents methodology for automatic co-registration of multi images with different coordinates. Two types of images are focused on, namely spaceborne fully polarimetric synthetic aperture radar (SAR) images and close-range photographs. Scale-invariant feature transform (SIFT) is applied to extract points observed in a pair of images. The points are regarded as ground control points (GCPs) for satellite images, and passpoints for photogrammetry. Hereafter, the points are referred as "common points". In the process of matching candidates of common points in each image, the nearest neighbor rule is used for initial matching. The two-way matching method is proposed to eliminate false matches. The proposed algorithm also removes matching points with large root mean squared error (RMSE) and refines the expected location of points through a first-degree polynomial wrapping method. In addition, information entropy and spatial dispersion quality constraints are used to quantify the spatial distribution of common points for robustness of matching. In terms of the fully polarimetric SAR registration, it was found that the location and combination of GCPs were different for each type of polarization data (HH, HV, VH or VV). Therefore, we propose co-registration using total power (TP) images, rather than each polarization image, to minimize the total registration error of all the polarization data. The proposed method is applied to imaging of four areas in Japan, namely, Chiba, Shinjuku, Kyoto and Sapporo. As a result, it was demonstrated that in almost all cases, the TP combination generated the least total RMSE of the automatic co-registration. On the other hand, it was examined to automatically estimate the orientation of dozens of close-range photographs using SIFT. The results demonstrated that the more pairs of photographs are processed, the higher accuracy of result is obtained. Therefore, we propose an acceptable approach to the automatic orientation for close-range photogrammetry.

Keywords: automatic co-registration, ground control points (GCPs), passpoints, polarimetric synthetic aperture radar (SAR), close-range photographs, scale invariant feature transform (SIFT)

1. INTRODUCTION

Co-registration of multi-temporal images is a crucial preprocessing step in several applications. Particularly in remote sensing system, an automatic co-registration methodology for SAR images should be capable of promptly generating an interferogram from interferometric SAR (InSAR) data when a natural disaster occurs. In term of photogrammetry, the extraction of passpoints from stereo-pair of photographs is essential to build the three-dimensional (3D) models. The complete procedure for image co-registration consists of four stages: feature extraction, feature matching, mapping function estimation and image transformation (Cheng *et al*., 2008). Image co-registration can be performed manually or automatically. In manual registration, the common points of the image pair are collected by visual interpretation. Even though this approach is well established, the procedure can lead to inaccurate results, and can be slow to execute, especially if a large number of images need to be registered. In addition, common points should be well distributed across the entire image so that the registration accuracy is stable. Therefore, the development of a method for automatic image co-registration is strongly needed to produce reliable and accurate results. In addition, the use of polarization data makes geometrical correction difficult because the same GCPs are not necessarily derived from different polarization images. Therefore, a superior image matching algorithm that can be applied to polarimetric SAR should be developed for adapting to a broad variety of geometric transformations and to provide robustness against noise.

Recently, scale-invariant feature transform (SIFT), proposed by Lowe (Lowe, 2004), has been widely used for automatic detection of feature points on images. SIFT is an approach to detecting and extracting local feature descriptors that are reasonably invariant with changes in illumination, image noise, rotation and scaling, as well as with small changes in viewpoint. SIFT detects keypoints by calculating the convolution of the image with Gaussian filters at different scales, and the generation of difference-of-Gaussian (DoG) images from the difference of adjacent blurred images. Local maxima and minima of the DoG images are detected from keypoints across different scales. After the keypoint's orientation is obtained, a keypoint descriptor is computed as a set of orientation histograms on the neighboring pixels. When SIFT eigenvectors of two images are generated, the Euclidean distance of eigenvectors of keypoints is used to measure the similarity of keypoints in two images. Then, the two keypoints that are nearest to each other in Euclidean distance are selected as a pair of matching points (Liu *et al.,* 2008).

In this paper, a robust methodology to achieve automatic common points extraction by using SIFT algorithm is proposed. The proposed method does not require any user intervention and allows for a flexible number of common points based on information entropy and spatial dispersion quality constraints because sufficient and well-distributed common points are required for suitable co-registration precision. In Section 2, the proposed method for automatic co-registration of multitemporal fully polarimetric SAR images is presented. Section 3 describes the automatic extraction of passpoints on stereo-pairs of photographs. The paper is concluded in Section 4.

2. AUTOMATIC CO-REGISTRATION OF MULTI TEMPORAL FULLY POLARIMETRIC SAR IMAGES

The proposed method for co-registration of multi-temporal and polarimetric SAR images is classified into two parts. The first is an automatic GCP extraction procedure, as shown in figure 1. The second is an automatic procedure for optimizing co-registration, as shown in figure 2.

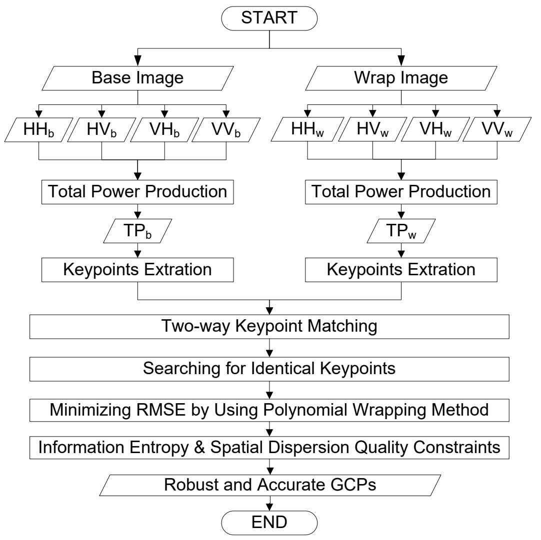


Figure 1: Automatic GCP extraction procedure

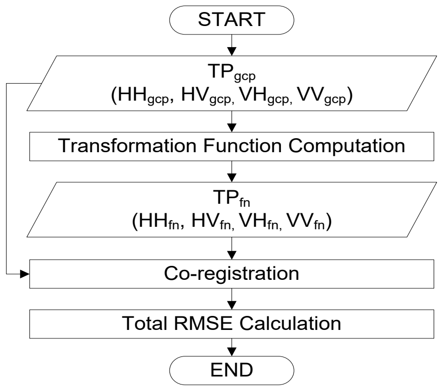


Figure 2: Automatic optimal co-registration procedure

2.1 Automatic GCP extraction procedure

The proposed method starts with the base (HH_b, HV_b, VH_b and VV_b) and wrap (HH_w, HV_w, VH_w and VV_w) of polarimetric SAR images. In the following, each step of the method is delineated. The total power (TP) received by the four channels of a polarimetric radar system can be calculated as the sum of the squares of the magnitude of all polarization data:

$$TP = \left|HH_{mag}\right|^2 + \left|HV_{mag}\right|^2 + \left|VH_{mag}\right|^2 + \left|VV_{mag}\right|^2 . \qquad (1)$$

2.1.1 Keypoint extraction with SIFT algorithm and filter strategies

The candidate keypoints are extracted with Lowe's SIFT algorithm. An extremely large number of candidate keypoints are extracted, which may contain many false matches. Therefore, the filter strategies namely, two-way keypoint matching, searching for identical keypoints and minimizing RMSE are used to exclude the false matches while preserving the correct ones. The matches are identified by finding the two nearest neighbors of each keypoint from the base image among those in the wrap image, and only accepting a match if the Euclidian distance to the closest neighbor is less than a threshold. By matching each keypoint from the base image to those in the wrap image and vice versa, the identical keypoints are identified by using two matching results which are obtained through the two-way matching method. To ensure that no false matches remain, the RMSE minimizing method is used by removing GCPs with the large errors and by refining the positions of the pixels. The first-degree polynomial wrapping method is applied by provides interpolation calculations using the following equations:

$$X_i^{'} = a_1 + a_2 x_i + a_3 y_i + a_4 x_i y_i, \quad Y_i^{'} = a_5 + a_6 x_i + a_7 y_i + a_8 x_i y_i \tag{2}$$

where x_i and y_i are the input source coordinates, X_i' and Y_i' are the retransformed coordinates, and a_1 to a_8 are polynomial coefficients.

2.1.2 Information entropy and spatial dispersion quality constraints

To quantify the spatial distribution of GCPs, the information entropy of local regions and the spatial dispersion quality are used and can be derived as

$$H_i = -\sum_{j=0}^{255} P_j \log_2 P_j, \tag{3}$$

where H_i is the entropy of local regions, j is the grayscale intensity value (0-255) and P_j is the probability of j within the region of interest. The index *Disp* is defined as

$$Disp = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x}_{wmc})^2 + \sum_{i=1}^{n}(y_i - \bar{y}_{wmc})^2}{n}}, (\bar{x}_{wmc}, \bar{y}_{wmc}) = \left(\frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}, \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \right). \tag{4}$$

Here, x_i and y_i are the coordinates of the point of interest, w_i is the weight of point i, and n is the number of points.

The *Disp* value expresses the quality of spatial dispersion: smaller and larger *Disp* values indicate worse and better spatial distribution, respectively. The maximum *Disp* is selected in order to define the number of GCPs for a co-registered image.

2.2 Automatic procedure for optimizing co-registration

In the proposed method, TP images are assumed to be used, and the function TP_{fn} is estimated by using GCPs, thus giving TP_{gcp}. For reference and comparison, the transformation functions of the original four polarization data (i.e., HH_{fn}, HV_{fn}, VH_{fn} and VV_{fn}) are calculated using each GCP (i.e., HH_{gcp}, HV_{gcp}, VH_{gcp} and VV_{gcp}). The first-degree polynomial method is adopted as the transformation function. The total RMSE is computed by applying the transformation functions obtained from dispersed GCPs of the HH, HV, VH, VV or TP combination to all four polarization data combinations (referred to as $RMSE_{total1}$), and by applying the transformation functions to all four polarization data and TP combinations, that is, five combinations in total (referred to as $RMSE_{total2}$). In fact, $RMSE_{total1}$ is an indicator for the validation of the co-registration and $RMSE_{total2}$ is a reference. The minimum total RMSE is used to examine the optimal transformation function that can be applied to any polarization data. The appropriate resampling algorithm (cubic convolution) is selected to meet the requirements of the application and register the images.

2.3 Experiment and discussion

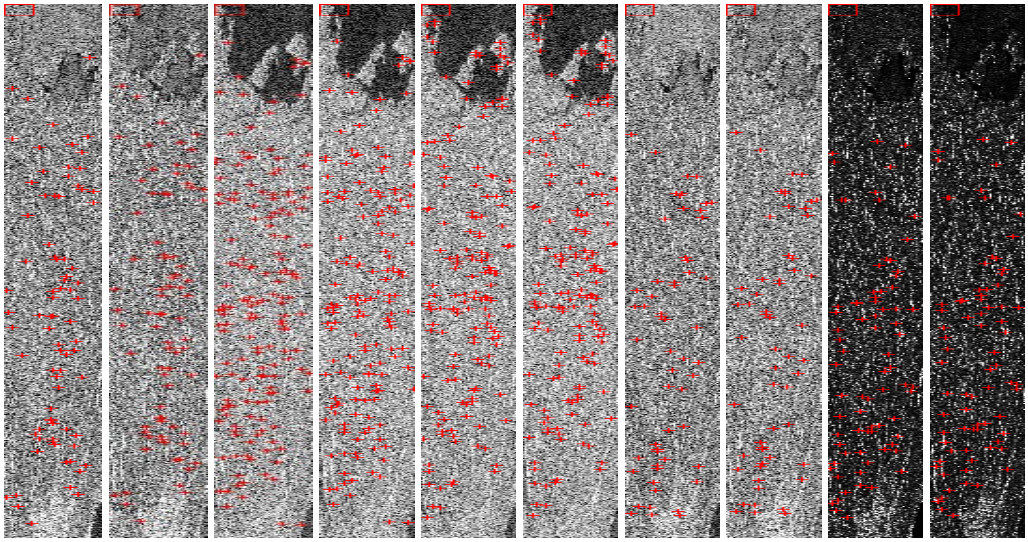
Table 1: Properties of multi-temporal and fully polarimetric SAR images

Properties	SAR images (ALOS-PALSAR, Level 1.1, CEOS format and HEOC)							
Area	Kyoto		Chiba		Shinjuku, Tokyo		Sapporo, Hokkaido	
Type	Base	Wrap	Base	Wrap	Base	Wrap	Base	Wrap
Acquired Date (yyyy/mm/dd)	2007/04/17	2009/04/22	2006/08/15	2007/04/02	2006/08/19	2006/10/04	2007/05/25	2008/11/27
Scene Center Latitude/Longitude	35.298 / 135.669	35.295 / 135.660	35.787 / 140.368	35.778 / 140.380	35.839 / 139.697	35.831 / 139.685	43.246 / 141.389	43.240 / 141.360
Size (Sample x Line)	1,248 x 18,432		1,280 x 18,432		1,088 x 18,432		1,088 x 18,432	
Orbit of Observation	Ascending		Ascending		Descending		Ascending	
Off-Nadir Angle	21.5		21.5		23.1		23.1	
Topography	Mountain areas; and Obama bay and Wakasa bay		Agricultural areas, some urban areas and Narita International Airport		Flat areas, commercial and residential areas		Urban areas, mountain areas and the Japanese Sea	

Table 2: GCP extraction results for multi-temporal and polarimetric SAR images

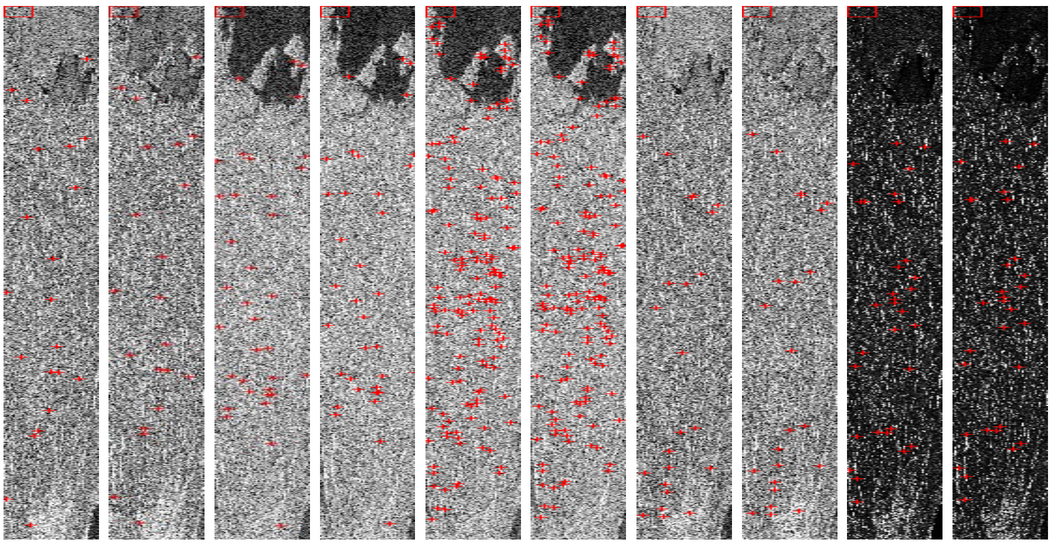
Images		Number of GCPs					RMSE				Maximum Dispersion Value ($\times 10^3$)	Computation Time (second)
Areas	Polarization	Two-way Matching B→W	Two-way Matching W→B	Identical	Minimizing RMSE	Dispersion	Identical	Revision	Refinement	Dispersion Quality		
Kyoto	HH	360	358	289	79	21	8.164	1.017	0.054	0.019	4.74	82
	HV	791	801	645	156	35	8.363	0.980	0.032	0.030	4.18	130
	VH	769	764	614	154	154	7.549	1.063	0.011	0.011	4.38	128
	VV	293	304	235	57	23	8.904	0.968	0.114	0.004	4.53	63
	TP	213	217	181	77	31	5.623	1.012	0.079	0.040	3.67	66
Chiba	HH	121	117	86	21	21	11.515	0.931	0.022	0.022	3.69	57
	HV	404	416	310	63	49	11.449	0.877	0.035	0.018	5.50	70
	VH	413	435	320	68	31	12.089	1.086	0.035	0.018	5.64	71
	VV	106	117	75	25	20	9.560	1.058	0.006	0.014	5.11	52
	TP	590	613	470	164	74	5.723	0.980	0.031	0.030	4.78	88
Shinjuku	HH	557	555	437	118	21	6.676	1.108	0.030	0.006	5.06	83
	HV	616	599	475	99	27	8.614	1.090	0.013	0.020	6.52	90
	VH	524	506	387	79	45	8.167	1.097	0.010	0.013	5.50	82
	VV	697	719	553	148	125	6.337	1.087	0.014	0.016	4.70	95
	TP	406	307	311	119	34	4.611	1.031	0.016	0.026	4.18	65
Sapporo	HH	349	356	275	52	34	9.902	0.948	0.098	0.053	2.99	89
	HV	459	449	352	80	35	8.684	1.103	0.031	0.013	4.52	78
	VH	449	446	339	58	55	8.795	0.998	0.026	0.061	4.33	80
	VV	235	220	179	36	30	8.197	0.921	0.166	0.088	2.48	65
	TP	831	838	675	221	30	5.992	1.066	0.058	0.018	4.56	145

Table 2 shows the number of GCPs and the RMSE in each consequent step of the proposed method. The RMSE in each consequent step was reduced continuously in all cases of the polarimetric SAR images including the TP images. The results after applying the two-way matching indicate that this filter strategy is rapid and effective for removing false matches. The RMSE minimization was considered in order to remove the large error of GCPs (i.e., revision) and implement re-positioning of GCPs (i.e., refinement) of wrap images. Consequently, the numbers of GCPs were decreased and the results are extremely accurate in terms of RMSE. In addition, the entropy information and spatial distribution quality constraints were utilized in order to quantify the spatial distribution of GCPs and to select robust GCPs. In a few cases, we found that RMSE slightly increased because points with very low RMSE were eliminated. However, because the effect of this phenomenon is small, the methodology is effective for selecting GCPs. Moreover, the computation time of the processes is short. Figure 3 and 4 show GCPs were obtained after refinement and spatial dispersion quality steps, respectively.



(HH_{base}) (HH_{wrap}) (HV_{base}) (HV_{wrap}) (VH_{base}) (VH_{wrap}) (VV_{base}) (VV_{wrap}) (TP_{base}) (TP_{wrap})

Figure 3: GCP extraction results for Kyoto area for base and wrap of HH, HV, VH, VV and TP with 1,248 × 18,432 pixel original images. GCPs are shown as red marks. The numbers of GCPs after minimizing RMSE are 79, 156, 154, 57 and 77, respectively



(HH_{base}) (HH_{wrap}) (HV_{base}) (HV_{wrap}) (VH_{base}) (VH_{wrap}) (VV_{base}) (VV_{wrap}) (TP_{base}) (TP_{wrap})

Figure 4: GCP extraction results for Kyoto area for base and wrap HH, HV, VH, VV and TP with 1,248 × 18,432 pixel original images. The numbers of GCPs remaining after applying the information entropy and spatial dispersion quality constraints are 21, 35, 154, 23 and 31 with the least RMSE (less than 0.04), respectively

Tables 3 to 6 show that in almost all cases, the TP combination generated the least total RMSE, although in Table 6 the total RMSEs ($RMSE_{total1}$) of the VH combination is slightly lower than the TP combination. This can be negligible, namely 0.01 differences in RMSEs. Let us consider the meaning of the proposed method. Equation (1) indicates that TP is the sum of each polarization power. Thus, TP images can be considered to express a combination of the characteristics of the four polarization images. It reasonably follows that the GCPs obtained from TP images reflect all four polarizations. Therefore, the proposed method is suitable for automatic co-registration of multi-temporal and polarimetric SAR images. Finally, in the experiment of the four areas include different types of topography. When we take a close look at the obtained results, no clear trend is found in the co-registration results. Therefore, the proposed method can function independently of land cover type.

Table 3: Total RMSE of the automatic co-registration for Kyoto in Japan

GCPs		Transformation Function of Kyoto				
POL	#	HH	HV	VH	VV	TP
HH	21	0.02	2.17	2.27	2.30	1.96
HV	35	2.10	0.03	1.71	1.49	1.72
VH	154	2.19	1.73	0.01	1.47	0.56
VV	23	1.80	1.45	1.19	0.00	0.51
TP	31	1.54	1.53	1.38	0.41	0.04
$RMSE_{total1}$	233	2.04	1.62	1.02	1.50	1.01
$RMSE_{total2}$	264	1.98	1.61	1.07	1.41	0.95

Table 4: Total RMSE of the automatic co-registration for Chiba in Japan

GCPs		Transformation Function of Chiba				
POL	#	HH	HV	VH	VV	TP
HH	21	0.02	2.03	2.48	2.89	1.92
HV	49	1.66	0.02	0.91	1.88	0.69
VH	31	1.12	1.09	0.02	1.44	0.90
VV	20	2.99	1.99	1.61	0.01	1.90
TP	74	1.76	0.78	0.89	1.74	0.03
$RMSE_{total1}$	121	1.71	1.29	1.35	1.85	1.28
$RMSE_{total2}$	195	1.73	1.13	1.20	1.81	1.01

Table 5: Total RMSE of the automatic co-registration for Shinjuku, Tokyo

GCPs		Transformation Function of Shinjuku				
POL	#	HH	HV	VH	VV	TP
HH	21	0.01	0.76	0.91	1.14	0.25
HV	27	0.82	0.02	1.37	1.09	0.64
VH	45	1.04	1.54	0.01	1.54	1.10
VV	125	1.29	0.74	1.47	0.02	0.10
TP	34	0.24	0.79	1.16	1.05	0.03
$RMSE_{total1}$	218	1.12	0.93	1.25	0.88	0.56
$RMSE_{total2}$	252	1.05	0.91	1.24	0.90	0.52

Table 6: Total RMSE of the automatic co-registration for Sapporo, Hokkaido

GCPs		Transformation Function of Sapporo				
POL	#	HH	HV	VH	VV	TP
HH	34	0.05	1.16	1.21	1.96	0.77
HV	35	1.72	0.01	0.52	2.94	0.56
VH	55	1.21	0.58	0.06	2.96	0.60
VV	30	1.86	1.49	1.41	0.09	1.55
TP	30	1.62	0.56	0.77	4.48	0.02
$RMSE_{total1}$	154	1.37	0.92	0.88	2.44	0.89
$RMSE_{total2}$	184	1.41	0.87	0.86	2.87	0.82

3. AUTOMATIC EXTRACTION OF PASSPOINTS ON STEREO-PAIRS OF PHOTOGRAPHS

When 3D building models are generated through photogrammetry, extraction of passpoints from stereo-pair of photographs is a key issue. In usual, it is time-consuming and an efficient method is desirable. In the present research, SIFT algorithm was examined for the efficient extraction of passpoints.

3.1 Applying SIFT algorithm to extraction of passpoints

In the preliminary examination, 25 stereo-pairs of photographs taken in the Old Quarter, Hanoi were used. As a result, it was found that many false passpoints were extracted. This may be caused by a large difference in shift and rotation between two viewing points shown in figure 5. In other cases, this sunlight condition difference may lower the accuracy of passpoint extraction. Therefore, photographs for stereo-pair were carefully reselected in terms of the viewing geometry and illumination.

(a) (b)

Figure 5: The example of the stereo-pairs that have many false extractions of passpoints. (a) The view points are different largely. (b) The date and time that the photographs was taken is different.

3.2 Removing the false extractions by using perspective projection equation

The extracted passpoints may include false one. Therefore, perspective projection equation is used in order to remove the false extractions. Perspective projection is represented by Equation (5). a_i, b_i and c_i denote coefficients. First a_i, b_i and c_i are estimated from the photographic coordinates of the extracted passpoints on the stereo-pair by using the least squares method. Next, each passpoints' RMSE defined by equation (6) is calculated from a_i, b_i and c_i. Finally, the passpoints whose RMSEs are bigger than a certain threshold are removed.

$$x' = \frac{a_1 x + b_1 y + c_1}{a_0 x + b_0 y + c_0}, \quad y' = \frac{a_2 x + b_2 y + c_2}{a_0 x + b_0 y + c_0} \tag{5}$$

$$RMSE = \sqrt{\left(x' - \frac{a_1 x + b_1 y + c_1}{a_0 x + b_0 y + c_0}\right)^2 + \left(y' - \frac{a_2 x + b_2 y + c_2}{a_0 x + b_0 y + c_0}\right)^2} \tag{6}$$

3.3 Result of simultaneous relative orientation for many successive stereo-pairs

Simultaneous relative orientation for reselected 40 stereo pairs is computed from the photographic coordinates of the refined passpoints by photogrammetry software (Image Master, Topcon). As a result, it was found that the simultaneous relative orientations of only successive 13 stereo-pairs were calculated successfully. The rest of stereo-pairs included some sets of two successive stereo-pairs whose passpoints didn't include tiepoint. Passpoint that is common to adjacent stereo-pairs is called a tie point as shown in figure 6. There must be tiepoint on each set of two successive stereo-pairs in order to determine the relative orientations of all stereo-pairs simultaneously. In the present research, some tiepoints were removed excessively in the refinery process.

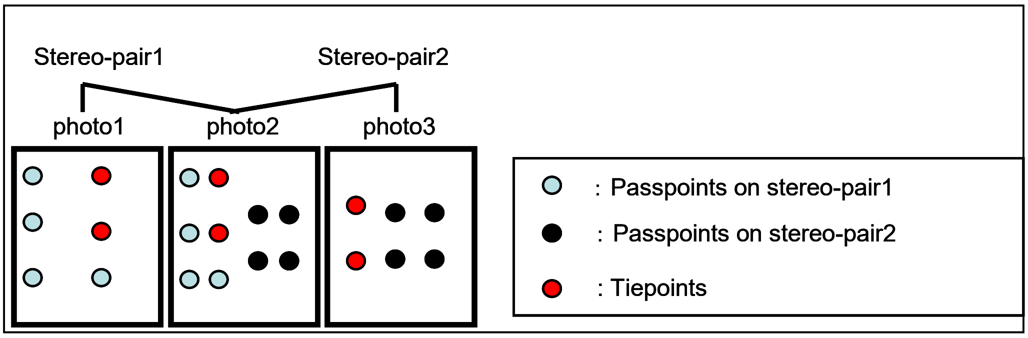


Figure 6: Tiepoint

The result of simultaneous relative orientation for 13 stereo-pairs is shown on Table 7. Residual y-parallax and residual error in each passpoint positions are often used as the indexes to represent the accuracy of relative orientation. In the result shown on Table 7, almost all of the values are less than one pixel, and the accuracy of simultaneous relative orientation is acceptable. In addition, the more accurate result was achieved after selecting manually three passpoints on image 30 and image 31 whose residual errors were large, removing them, and computing simultaneous relative orientation again.

Table 7: Result of simultaneous relative orientation

Image No.	Before manual refinement		After manual refinement	
	Residual y-parallax (pixel)	Residual error in each passpoint positions (pixel)	Residual y-parallax (pixel)	Residual error in each passpoint positions (pixel)
27-28	0.09	0.36	0.09	0.36
28-29	0.65	0.52	0.65	0.52
29-30	0.92	2.17	0.92	0.60
30-31	6.42	2.17	1.04	0.60
31-32	0.33	1.95	0.33	0.47
32-33	0.19	0.45	0.19	0.37
33-34	0.73	0.40	0.73	0.37
34-35	0.39	0.33	0.39	0.28

Image No.	Before manual refinement		After manual refinement	
	Residual y-parallax (pixel)	Residual error in each passpoint positions (pixel)	Residual y-parallax (pixel)	Residual error in each passpoint positions (pixel)
35-36	0.10	0.27	0.10	0.20
36-37	0.19	0.28	0.19	0.21
37-38	0.56	0.32	0.56	0.27
38-39	0.21	0.32	0.21	0.27
39-40	0.26	0.23	0.26	0.13

4. CONCLUSION

To increase the robustness and accuracy in automatic co-registration of multi images with different coordinates, the proposed method has been introduced as follows. The keypoints were extracted based on SIFT algorithm. Two-way keypoint matching was proposed to reduce the number of unstable correspondence keypoints. The first-degree polynomial wrapping method predicts coordinates of the GCPs candidates, and the candidates with large error are removed. In term of close-range photographs, the perspective projection equation was used to eliminate the false extracted passpoints. By using the information entropy and spatial dispersion quality constraints, only common points with high-quality spatial dispersion distribution are selected. The SAR image matching produced the high rate of correct matches and the relative orientations of stereo-pairs were computed with higher accuracy. In automatic co-registration, the transformation function of the TP combination generated the least total RMSE, and is reasonable to apply to dispersed GCPs extracted from the other four polarization data. The proposed method can be successfully applied to automatic co-registration for full scene multi-temporal and polarimetric SAR images. In addition, the acceptable approach can be implemented to the automatic orientation for close-range photogrammetry.

REFERENCES

Cheng, L., Gong, J., Yang, X., Fan, C., and Han, P., 2008. Robust affine invariant feature extraction for image matching. *IEEE Geoscience and Remote Sensing Letters*, 5 (2), 246-250.

Liu, J., and Yu, X., 2008. Research on SAR image matching technology based on SIFT. Proc. of 21st International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 37 (part B1), 403-408.

Liu, L., Wang, Yu., and Wang, Yi., 2008. SIFT Based Automatic Tie-Point Extraction for Multi-temporal SAR Images. International Workshop on Education Technology and Training & 2008 International Workshop on Geoscience and Remote Sensing, 1, 499-503.

Lowe, D. G., 2004. Distinctive image features from scale-invariant keypoints. International Journal of Computer Vision, 60 (2), 91-110.

Wessel, B., Huber, M., and Roth, A., 2007. Registration of near real-time SAR images by image-to-image matching. Proc. of Photogrammetric Image Analysis, 179-184.

Automatic three-dimensional modeling of buildings in dense urban areas using airborne LiDAR

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ABSTRACT

These years in Japan, the demand for three-dimensional (3D) urban model is growing in various applications, such as preparedness to fire spread caused by earthquakes. Airborne LiDAR (Light Detection and Ranging) has been reported to be potential to effectively generate 3D urban model because it measures point clouds containing 3D coordinate which may be easily processed into the 3D model. For this purpose, the technique to classify the point clouds into each house unit is required, but it is found that existing algorithms cannot function effectively especially in the districts where Japanese traditional houses exist because they have almost same height of slant roofs, which are difficult to distinguish from each other. In the present research, an algorithm was developed to automatically generate 3D models using airborne LiDAR, focusing on the accurate extraction of the norms of roof planes and the estimation of roof combination. This algorithm requires tuning of several critical thresholds, i.e. horizontal and vertical distances between houses, and the maximum error to the estimated roof plane. While the system still needs to improve the optimization of such thresholds, it generates 3D models of the Japanese traditional houses more accurately than the existing algorithms.

Keywords: airborne LiDAR, building model, dense urban area, algorithm

1. INTRODUCTION

Urban building models are expected in various fields and laser scanner is capable of providing three-dimensional (3D) data necessary for the modeling. As the data acquired using laser scanner are point clouds, modeling is required to classify point clouds into a certain categories. Biosca and Lerma (2008) proposed an unsupervised robust clustering approach based on fuzzy methods for the segmentation of huge volume of terrestrial laser scanning data.

Airborne laser scanner is capable of estimating the building height and simple building models can be produced using airborne LiDAR (Light Detection and Ranging). Existing researches focused on modeling of buildings fusing airborne laser scanner and other sources, e.g. satellite imagery (Sohn and Dowman, 2007), aerial imagery (Huber et al., 2003) and terrestrial LiDAR (Haala et al., 2007)

(Caceres et al., 2007). While terrestrial LiDAR provides detailed data of side surfaces of buildings, airborne LiDAR has potential to meet the demand to generate building models in a wide area.

However, in the dense urban areas in Japan, modeling of buildings using airborne LiDAR data is challenging. In dense urban areas where gable-roof houses and hip-roof houses are popular, some of houses with the same height of gable roofs are located very closely to each other, and it is quite difficult to identify the boundaries of the houses from ALS.

Therefore, in the present paper, the authors report an algorithm to generate three-dimensional building models in dense urban areas using airborne LiDAR.

2. STUDY AREA

Kyoto is famous as the old Japanese capital city, and it still has plenty of traditional houses and landscape. The area in Higashiyama-ku, Kyoto was selected as study area. The area is famous for traditional temples and shrines, and it is a hilly area. Figure 1 shows Ninen-zaka near Kiyomizu-temple. Three-dimensional building models in this area are desired for the planning of the preservation of old temples against fire caused by earthquake. The details on the used airborne LiDAR are shown in Table 1.

Figure 1: Ninen-zaka, Higashiyama-ku, Kyoto

Table 1: Details on airborne LiDAR

Measurement date	June 2002 to February 2003
Density	Approximately 1 point / m^2
Altitude	900 to 1,000m
Horizontal accuracy	±50cm
Vertical accuracy	±15cm

3. ALGORITHM OF 3D BUILDING MODELING IN DENSE URBAN AREA

Following is a procedure of the algorithm of 3D building modeling in dense urban area using airborne LiDAR data.

(1) Estimating digital terrain model (DTM) and filtering to separate point clouds on roof from the other point clouds, such as the point clouds on road, river,
(2) Classification of the roof point clouds into individual roof, and estimation of roof type,
(3) Delineation of roof boundary, and
(4) Estimation of height to DTM and generation of 3D building model.

4. FILTERING OF POINT CLOUDS TO DISCRIMINATE ROOF DATA

Airborne LiDAR measures the reflectance from the surface of the objects on the surface, i.e. building, tree or road. Three-dimensional modeling of buildings from airborne LiDAR requires preprocessing to separate point clouds on roof from the other point clouds. In essence, points with local minimum height are extracted, and then DTM is estimated using the points. However, our preliminary examination confirmed that the traditional algorithm cannot estimate DTM when the area is hilly like the study area in the present research or the area has a river which runs lower than roads. The present paper reports an algorithm to extract points which should be on DTM by examining the connectivity to local minimum height points. Hereafter, the procedure is described.

(1) Search the points around the point with local minimum height and select the points which meet vertical and horizontal difference between the local minimum height points. There points are regarded as “candidate of points on DTM”. This is shown in Figure 2.
(2) Using candidate points within a certain range, estimate a plane using least square method (LSM)
(3) Among non-candidate points, select the points which meet following conditions:
    (i) The horizontal distance from the point to the candidate point is within a threshold, and
    (ii) The distance from the point to the estimated plane is within a threshold.
(4) The point selected in (3) is newly regarded as a candidate point on DTM and is used for another searching in (2).
(5) Repeat (2) to (4) and finish when no DTM candidate point is available.
(6) Generate DTM through interpolation using DTM candidate points.
(7) Extract point clouds on roof when the distance from the point to DTM is larger than a threshold.

The extracted DTM is shown in Figure 3. If DTM is accurately estimated, the difference between DTM and DSM of the data near the roads should be quite small. This difference can be a good indicator for the DTM validation. Therefore, as for the data with less than 50 cm difference between DTM and DSM, the difference was examined. As a result, the data with less than 50 cm difference between DTM and DSM were 3,583 points among 20,118 points, and the mean of the difference was -0.006 m. The negative figure indicates the DTM was lower than the DSM. In addition, 2,792 points, approximately 78 % of 3,583 points were within ± 10 cm difference range. These results indicate that the proposed algorithm can accurately estimate DTM.

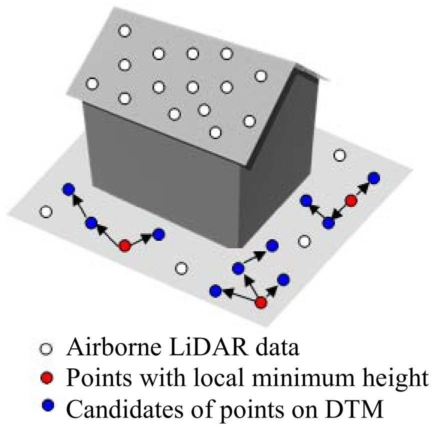

Figure 2: Searching points around points with local minimum height

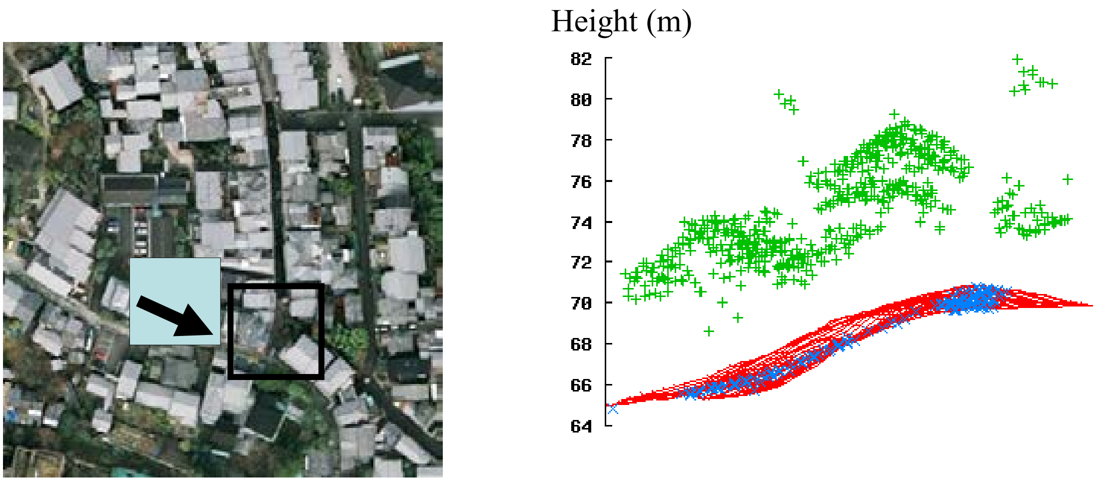

Figure 3: Extracted roof point clouds. (Left) area for the extraction is expressed with a box. (Right) blue points denote ground points, green points denote roof points and red mesh denotes the estimated DTM. Viewing direction is expressed in the left figure.

5. CLASSIFICATION OF ROOF DATA

Traditional Japanese houses, such as gable-roof houses or hip-roof houses shown in Figure 4, are arranged so that roof ridges are parallel or orthogonal in Figure 5. Proposed algorithm utilizes this feature. First, planes are estimated using several points. Next, histogram of azimuth angle of the plane norm is generated, and the peak of the histogram is determined. This peak indicates main direction of roof ridges. Then, after the main direction is determined, the azimuth angle space in Figure 6 is divided into four zones. Finally, according to the azimuth angle of each plane norm, roof points are classified into subgroups. The classification result in Figure 7 indicates that while the discrimination of roofs in both sides of the ridge was successful, roofs of several houses on the same side are still unclassified.

To solve this problem, distance to the planes estimated from points is used as a classifier. The result of this classification is shown in Figure 8. As a result, points were classified into several groups which are consisted of one or two roofs. Five houses can be found in Figure 8. Left two houses have a quite small difference in roof height, approximately less than half a meter. Similarly, right two houses have a similar difference. Therefore, the points of those houses still remained unclassified at this stage.

Here, feature of points around ridges is focused on. Assuming gable-roof houses, roofs on both sides of the ridge are symmetric to the ridge in most of the gable-roof houses. Thus, the plane norm obtained from points can be a key to matching a pair of roofs of a house. This feature can be applied to discriminate other types of houses. The results of the implementation are shown in Figure 9. For example,

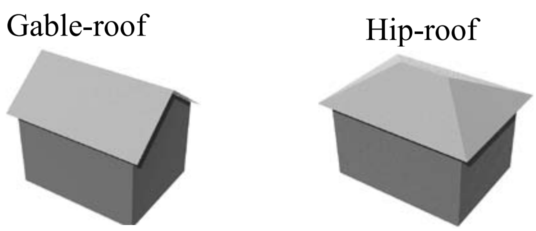

Figure 4: Traditional Japanese houses

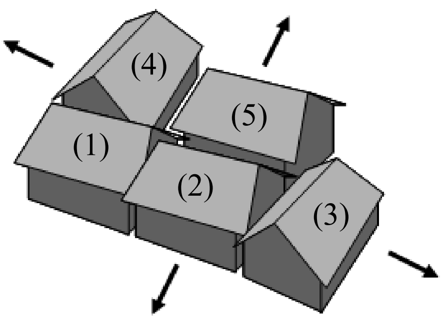

Figure 5: Spatial arrangement of traditional Japanese houses

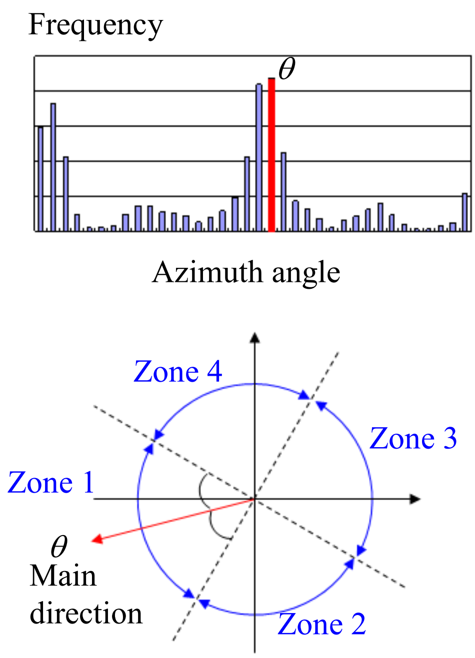

Figure 6: Determination of main direction

middle pair of roof was successfully extracted, but relationship of 1 roof to 2 roofs can be found. In this research, if such 1 to 2 matching relationship is found, two pairs are generated by dividing into or merging subgroups. Figure 10 exhibits the concept of this pair generation. The results of the pair generation are shown in Figure 11. It demonstrates that points were successfully classified into each roof and each house.

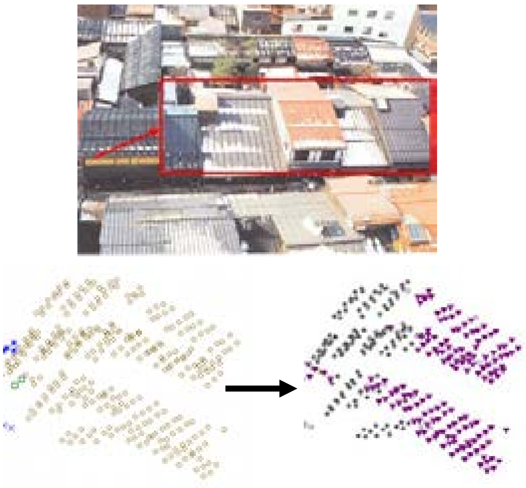

Figure 7: Classification using main direction

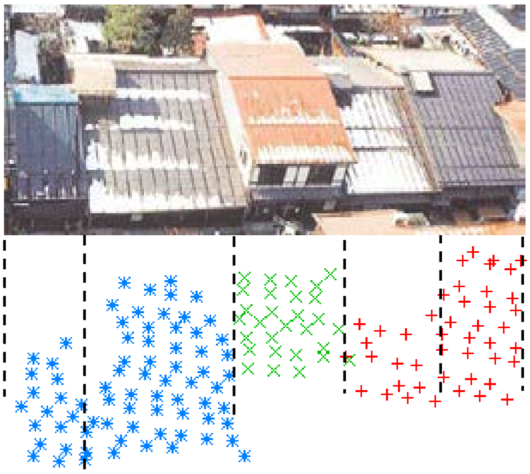

Figure 8: Classification of points into roofs

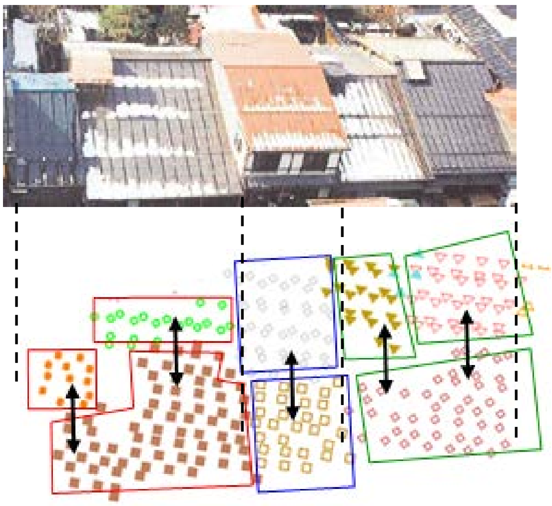

Figure 9: Classification of points considering the symmetry to the roof ridge

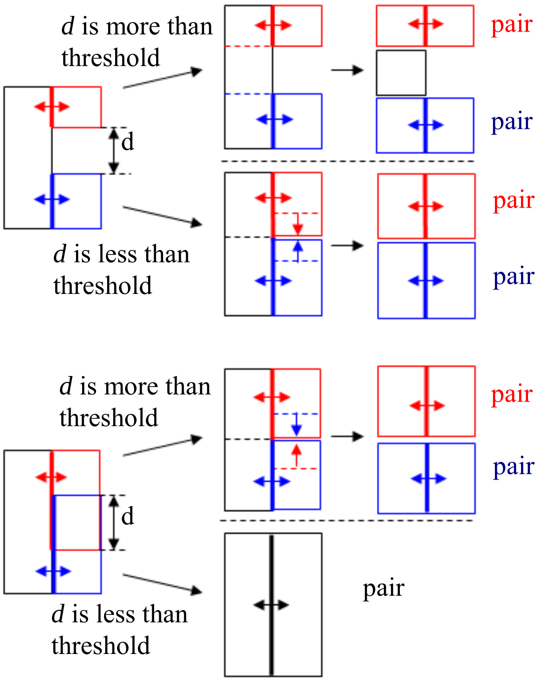

Figure 10: Generation of roof pair

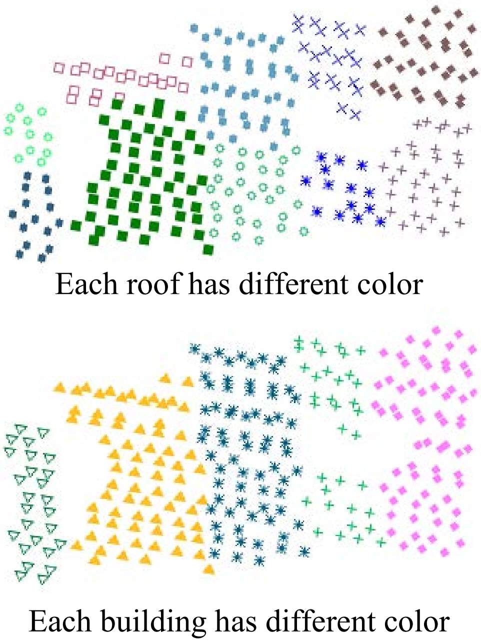

Figure 11: Matching roofs by generating roof pairs

6. DELINEATION OF ROOF BOUNDARY AND GENERATION OF WIREFRAME MODEL

Until the processing above, points are classified into each building. Modeling requires the boundary of the buildings. It is assumed that most of buildings in the dense urban areas in Japan have rectangular boundaries or boundaries consisted of a few rectangles when the buildings are projected to the ground. The sides of the rectangle are estimated so that they are parallel or orthogonal. In addition, the norms of a pair of gable or hip roofs are modified so that they are symmetric to the ridge. As shown in Figure 12, three-dimensional wireframe models with different types of roofs are generated by referring the height to DTM. Finally, 3D wireframe models were produced using the proposed algorithm. The models from the nadir view are shown in Figure 13.

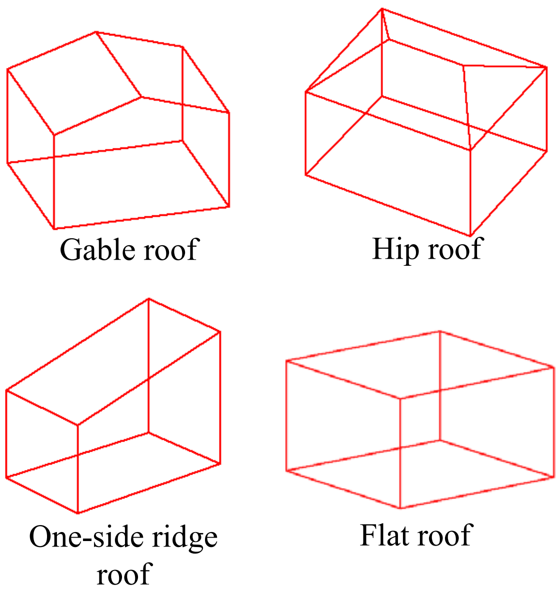

Figure 12: Wireframe models of different types of roofs

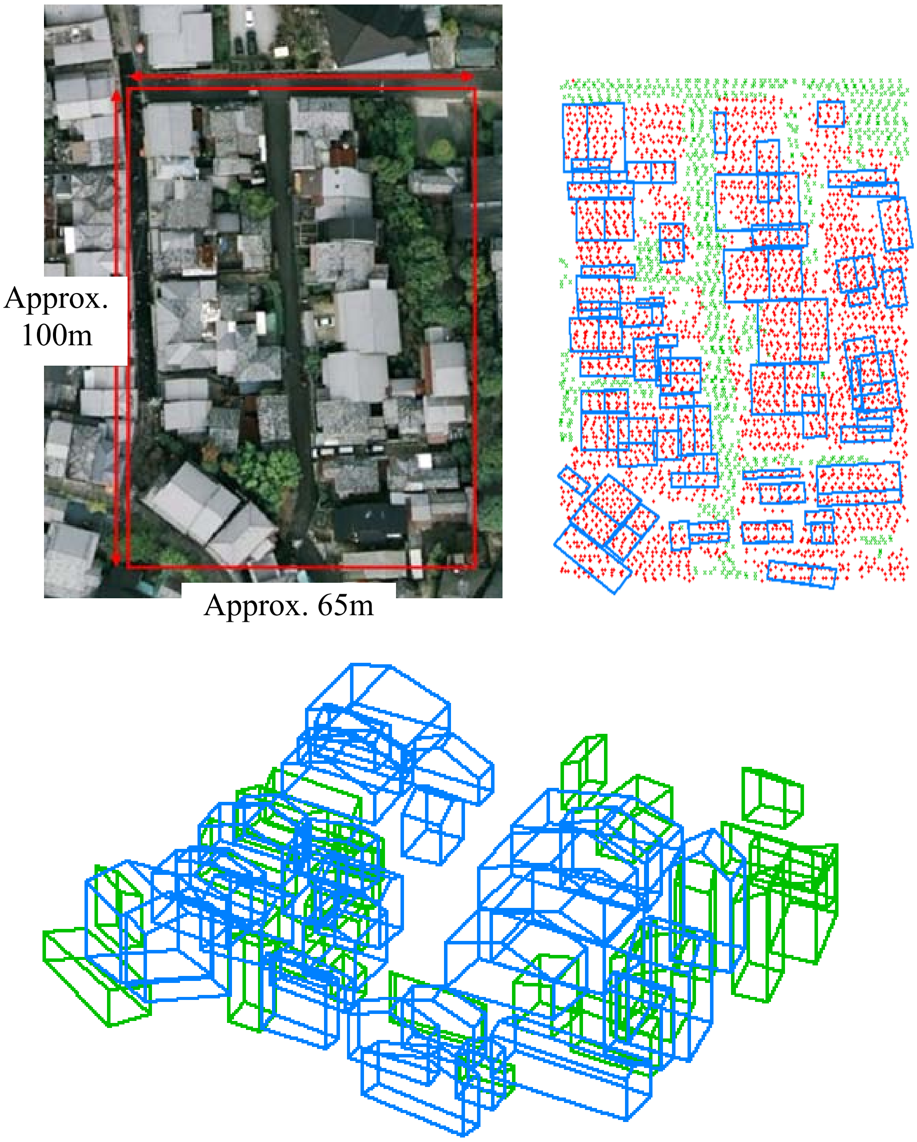

Figure 13: Three-dimensional wireframe model. (Upper left) area photograph. (Upper right) extracted models with filtering result. Red point denotes roof, green point road and blue frame building boundary. (Bottom) extracted models where blue flame denotes gable-roof house, purple hip-roof, green one-side-ridge-roof, and red flat-roof.

7. DISCUSSIONS

Figure 13 demonstrate that relatively large houses are successfully extracted and modeled, but that it failed to model some of small roofs, accordingly small houses. This was partly due to the low airborne LiDAR density. When less number of LiDAR data was available on a roof, i.e. a few points, identification of a roof plane was difficult and the points on a roof plane were misclassified into different roof planes. To avoid this misclassification, adjustment of threshold, e.g. thresholds for horizontal and vertical distances, is one of the effective countermeasures. However, the threshold optimal for the small house extraction is not always optimal for the large house extraction. This tuning of the threshold is a difficult issue and one of the approaches is to tune it in accordance with the average size of houses. This will be one of the future tasks.

In addition to the number of extracted buildings, size of the extracted buildings is discussed here. When the estimated size is smaller than the actual size, it is because the LiDAR data were not enough to identify the actual boundary. When the horizontal or vertical distance between points is larger than designated thresholds, the points are classified into separate groups. Therefore, when modeling in the dense urban area using the proposed methodology, more density of airborne LiDAR than the used data will be preferable, e.g. 1.5 points / m^2.

Contrary, there were some houses whose estimated sizes were larger than the actual sizes. In such cases, it was confirmed that roof heights of houses were almost same, and classification of points into individual roofs was not successful. This problem shares the cause with another problem, overlapping of extracted roofs. When the classification is not successful and roof shape is assumed as rectangle, overlapped oversize roof will be extracted. To avoid this failure, it should be checked whether extracted roofs are not overlapped to each other. If it is overlapped, the roof's shape should be modified. In this regard, this modification will be valid for simple rectangular roofs. When it comes to houses with non-rectangular boundary, it may be difficult to automatically model them in the dense urban areas.

Finally, discrimination of trees should be referred. At the stage of filtering to discriminate roof points in the proposed algorithm, the threshold of height for the roof points from DTM was set as 3.0 m. As a result, points reflected from tall tree were also included in the roof points, and building models were produced where tall trees exist. To exclude this failure, a technique to use standard deviation of height per unit area can be useful to separate roof points from tree points. This separation will be examined near future.

8. CONCLUSIONS

In this paper, an algorithm was reported to automatically generate three-dimensional building models in dense urban areas using airborne LiDAR. The algorithm starts with filtering to separate point clouds on roof. Next, roof point clouds are classified into individual roofs, and roof type is estimated. To classify roof point clouds into individual roofs, arrangement of traditional Japanese houses and norm of roof planes are utilized. Further classification requires examining roof plane arrangement on both sides of roof ridge. After roof boundary is delineated, finally, height to DTM is estimated and 3D building model is generated. The proposed filtering functioned quite effectively even in the dense urban and hilly areas. In addition, generated 3D wireframe models were acceptable in terms of the number and size of extracted buildings. However, there still remain a few future tasks such as roof overlapping and invalid modeling caused by misclassification of points from tall trees. In addition, the developed algorithm requires tuning of several critical thresholds, i.e. horizontal and vertical distances between houses, and the maximum error to the estimated roof plane. While the algorithm still needs to improve the optimization of such thresholds, it generates 3D models of the Japanese traditional houses more accurately than the existing algorithms. In future, these tasks will be solved through further analysis.

REFERENCES

Biosca, J.M., and Lerma, J.L., 2008. Unsupervised robust planar segmentation of terrestrial laser scanner point clouds based on fuzzy clustering methods. *ISPRS Journal of Photogrammetry and Remote Sensin*, 63, 84-98.

Caceres, J.J., and Slatton, K.C., 2007. Improved classification of building infrastructure from airborne Lidar data using spin images and fusion with ground-based Lidar. *Proceedings of 2007 Urban Remote Sensing Joint Event*.

Haala, N., Becker, S., and Kada, M., 2007. Cell decomposition for building model generation at different scales. *Proceedings of 2007 Urban Remote Sensing Joint Event*.

Huber, M., Schickler, W., Hinz, S., and Baumgartner, A., 2003. Fusion of LIDAR data and aerial imagery for automatic reconstruction of building surfaces. *Proceedings of 2nd GRSS/ISPRS Joint Workshop* on “Data Fusion and Remote Sensing over Urban Areas”, pp. 82-86.

Sohn, G., and Dowman, I., 2007. Data fusion of high-resolution satellite imagery and LiDAR data for automatic building extraction. *ISPRS Journal of Photogrammetry and Remote Sensing*, 62, 43-63.

Trend of International Charter for Environmental Disasters

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ABSTRACT

The International Charter has been established for providing a system of space data acquisition and delivery to those affected by natural or man-made disasters. Each member agency is requested to commit resources to support the Charter and thus is helping to mitigate the impacts of disasters on human life and property. In 2010, nineteen organizations are involved in this activity. The Charter deals with cyclone, earthquakes, fire, floods, oil spills, volcanoes and other disasters. The charter activation started in 2000 and the number of activated charter is increasing. We analyzed the trend of disaster charters for environmental issues which might be strongly correlated with global environment changes. Strong cyclone, severe forest fire, and heavy flooding were the main environmental disasters in this Charter. Different remote sensing characteristics as well as preprocessing system influenced their applicability for disaster mitigation

Keywords: remote sensing, disaster charter

1. INTRODUCTION

Many disaster management policies and programs have been developed and implemented in the last decade in many countries, both in developing and developed countries. Efforts of such disaster management programs are very important, especially in spatial analysis involving modeling, visualization, satellite data, socio-economic data, and field data.

Satellite remote sensing data provide historical databases and their products now have a history of over three decades in terms of land cover datasets and recent products have significant high resolutions, both temporally and spatially.

Data and information derived from earth observation satellite have been used for a wide range of application in disaster management. Image-based damage mapping is constrained by the spatial resolution of the available data and the average size of the destroyed objects. Suitable sensors are also constrained by their actual availability, a function of positioning and pointing capabilities of the system.

GIS systems have been used for combining remote sensing data with other relevant data for risk analysis and assessment. Using these capabilities of GIS and visualization analysis, risk assessment maps are produced. This serves as warning information which is useful for mitigating disasters.

There are number of space-based information which is available to the disaster management community. International initiative such as GEOSS, IGOS-P and Sentinel Asia are helping the space community take on stronger role in solving the problems on the earth, including disasters.

This report aims to review these international activities using space-based information for disaster mitigation, especially focussing on the International Charter.

2. INTERNATIONAL ACTIVITIES

2.1 IGOS-P

The IGOS-P (the Integrated Global Observing Strategy Partnership) is an international partnership established in June 1998, which brings together a number of international organizations concerned with the observation of global environmental issues, from a research pint of view as well as from an operational one. For instance, the IGOS GeoHazards Theme was established as the initiative of three IGOS members, UNESCO, CEOS (Committee on Earth Observation Satellite) and ICS (International Council for Science).

2.2 UNISPACE III

UNISPACE III with the theme 'Space benefits for humanity in the twenty-first century' was held in Vienna in 1999. The Vienna Declaration on Space and Human Development was adopted as the output of the conference, in which 33 specific actions were recommended that should be carried out to enable space technologies to contribute to the global challenges of the new millennium.

One of the recommendations was the need 'to implement an integrated, global system, especially through international cooperation, to manage natural disaster mitigation, relief and prevention efforts, especially of an international nature, through Earth observation, communications and other space-based services, making maximum use of existing capabilities and filling gaps in worldwide satellite coverage'. The recognition of this need has led to a number of international initiatives that have been contributing to help developing countries access and use space-based information for disaster management (Stevens, 2008).

2.3 INTERNATIONAL CHARTER

The International Charter 'Space and Major Disasters' is an example of an initiative specific to disasters, which aims to achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters (Disaster Charter).

At the UNISPACE III, a proposal to create a charter that would provide a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users was discussed. ESA (European Space

Agency) and CNES (Centre National d'Etudes Spatiales) signed the Charter in June 2000. The Canadian Space Agency followed them and there are nineteen members in 2010. Each member agency has committed resources to support the Charter activities and thus is helping to mitigate the impacts of disasters on human life and property.

2.4 UN-SPIDER

The ad-hoc expert groups developed a number of important space-related initiatives that could support different phases of disaster management, such as GEOSS (Global Earth Observation System of Systems), the International Charter 'Space and Major Disasters', IGOS-P, GMES (the Global Monitoring of Environment and Security) and the Sentinel Asia.

The United Nations General Assembly agreed to establish UN-SPIDER (Space-based Information for Disaster Management and Energy Response) in 2006 to provide universal access to all types of space-based information and services for disaster management. Their objectives are to be a gateway to space information for supporting disaster management, to be a hub to connect the disaster management and space groups, and to be a facilitator of capacity building. The UN-SPIDER works closely with end-users, particularly in developing countries, through a network of regional support offices.

2.5 HYOGO FRAMEWORK

The importance of space technology to support disaster preparedness was also recognized at the World Conference on Disaster Reduction, held in Kobe, in January 2005. Representatives from 168 countries recognized the contribution of space technology to disaster reduction and emphasized the need to incorporate with space-based services to support risk reduction.

A list of commitments is set out as the document, the 'Hyogo Framework of Action 2005-2015: Building the Resilience of Nations and Communities to Disasters'. The document was adopted by the General Assembly in 2005 (United Nations, 2005). The Hyogo Framework recognizes the need to 'promote the application of *in situ* and space-based earth observations, space technologies, remote sensing, GIS, hazard modeling and prediction, weather and climate modeling and forecasting, communication tools and studies of the costs and benefits of risk assessment and early warning'.

2.6 GEOSS

The Global Earth Observation System of Systems (GEOSS) integrates Earth observations with other information to help planners reduce vulnerability, strengthen preparedness and early-warning measures and, after disaster events, rebuild housing and infrastructure with low future risks.

GEOSS is also working to reduce risk over the long term by providing a better understanding of the relationship between natural disasters and climate change.

By making it possible to integrate different types of disaster-related data and information from diverse sources, GEOSS aims to strengthen analysis and decision making for disaster response and risk reduction.

GEOSS coordinates many complex and interrelated issues simultaneously. This approach avoids unnecessary duplication, encourages synergies among systems and ensures economic, societal and environmental benefits.

2.7 SENTINEL ASIA

Sentinel Asia is a voluntary basis initiative led by the APRSAF (Asia-Pacific Regional Space Agency Forum) to support disaster management activity in the Asia-Pacific region by applying the Web-GIS technology and space based technology, such as earth observation satellites data.

JAXA (Japan Aerospace Exploration Agency) makes strong commitment to this activity together with many international organizations. The participating institutions from within the region are able to access ALOS data to support monitoring wildfire and flood. The project also provides capacity building.

3. CONDITIONS OF INTERNATIONAL CHARTER

By the end of August 2010, the Charter had been activated 266 times in response to cyclones, earthquakes, forest and bush fires, floods, oil spills, volcanoes and others. The Charter has successfully demonstrated the importance and the benefit of producing timely satellite-based information to support emergency response.

3.1 Satellite Data

More than 100 products were developed and delivered last one and a half years and about a half of them were images related to flooding caused by heavy rains and cyclones (Fig. 1).

Landsat has a history of more than 30 years and has been used as a main satellite data for various fields. Main satellite data used for the Disaster Charter were MERIS, ASAR, Landsat, Aster, PALSAR, RADARSAT, AVNIR, SPOT, Formosat, TerraSAR, QuickBird, GeoEye and others, in order of spatial resolution of sensors. Most of the data have higher ground resolution than Landsat (Figure 1). The spatial resolution, for example, of QuickBird and GeoEyes are about 60 cm and 40 cm, respectively.

Although previous conditions of the disaster affected area are important for damage assessment, these new sensors have short history of their data storage. Other disadvantages of high spatial resolution satellite are their long revisit time and small spatial coverage area. Therefore it is sometimes necessary to introduce Landsat and other lower resolution satellite data for disaster assessment coupled with recent high resolution data in spatially and radiometrically (Fig. 2). The composition techniques of various types of satellite sensors are indispensable.

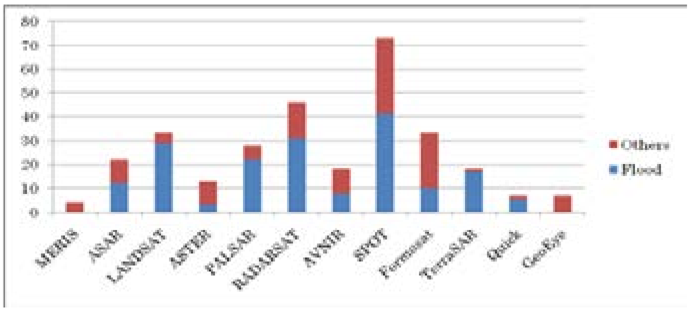

Figure 1. Number of satellite data used for the products of the Disaster Charter in 2009 and 2010

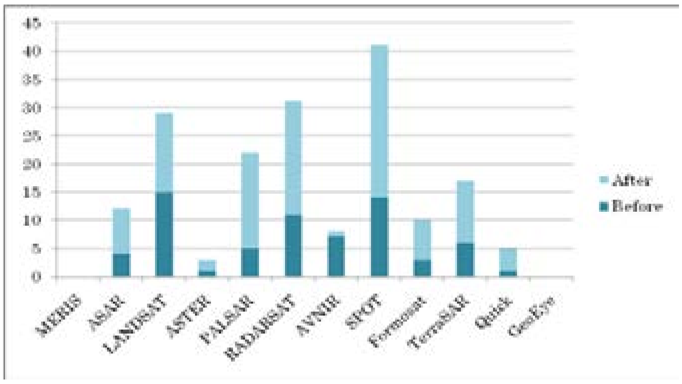

Figure 2. Number of satellite data (before and after the events) used for the products of the Disaster Charter in 2009 and 2010

3.2 Available data

The average days of satellite data observed after disaster events in 2009 and 2010 (until Aug.) were 4.0 days. Fig 3 shows that most of the data were observed within a few days after disaster events occurred.

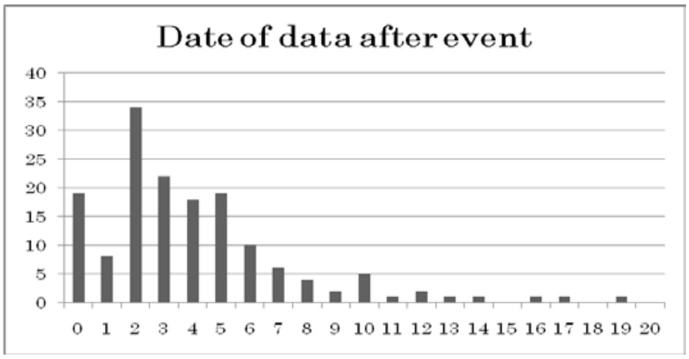

Figure 3. Number of satellite data used for the Products (x: date of satellite data observed after disaster events)

3.3 Processing days

The average days used for creating Products after satellite observation was 4.1 days and more than a half of the processing was done within 3 days. Some new Products could be found even 20 days after. Most of these data were delivered for rehabilitation purposes with very high spatial resolutions.

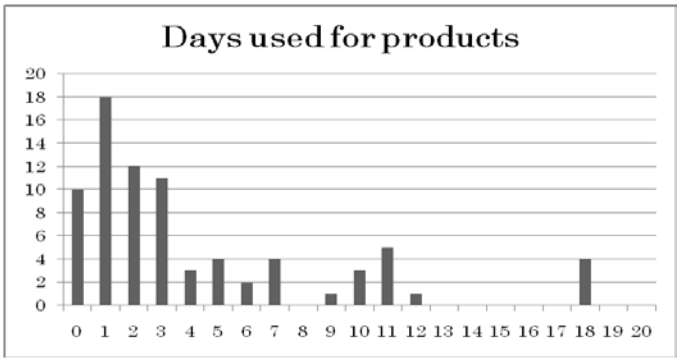

Figure 4. Number of products of the Charter
(x: days after satellite data were collected)

4. DISCUSSIONS

Recent products have significant high resolutions, both temporally and spatially. Landsat and other medium resolution satellite, however, still have important roles related to their large area coverage and historical databases.

Current distribution of map products is almost entirely internet-based, which allows rapid circulation.

Although there have been worldwide contribution of remote sensing experts to disaster mitigation, there is no single global coordination mechanism to implement an integrated disaster monitoring system. At least a gateway to connect disaster datasets must be implemented in some international organization for non-expert users.

The International Charter provides on demand access to space-based information for emergency response. But there is still the need to help the end user transform such information into usable products and introduce these products into their activities. The Charter was activated and damage maps were produced, but knowledge from the field is seldom incorporated in the process. User workshop or conference must be required for making the international activities more useful in collaborations among users and data distributors.

REFERENCES

Disaster Charter, http://www.disasterscharter.org/home
Sentinel Asia, http://dmss.tksc.jaxa.jp/sentinel2/topControl.action
Stevens, D., 2008. Increasing the Use of Geospatial Technologies for Emergency Response and Disaster Rehabilitation in Developing Countries, Nayak S. and S. Zlatanova (editors), *Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters*, Springer, 57-71.
United Nations, 2005, Report of the World Conference in Disaster Reduction, 42 p., http://www.unisdr.org/eng/hfa/docs/Final-report-conference.pdf

Risk management of cultural heritage in Kyoto

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ABSTRACT

The field of cultural property protection is wide and varied, with the problem of natural disaster alone having been overlooked. This lack of attention is particularly prevalent in measures for seismic hazard. Experts in the field of cultural property preservation recognize that cultural property fire-prevention measures thus far, having focused on accidental fires and arson within the precincts of shrines and temples, have been ineffective in preventing fires from spreading to historical buildings during simultaneous outbreaks of fire in surrounding areas where are of concern during an earthquake. In the Great Hanshin-Awaji Earthquake of 1995 Kyoto was shaken by seismic intensity 5 , but damage was relatively slight. In some instances, such as famous temples with high prestige at Ninnaji and Daigoji temples, the firefighting equipments were disrupted, precluding efforts to extinguish the flames. Kyoto is located some 50 or 60 km away from Kobe. Since the densely populated Kyoto basin of today is covered with flammable materials, if multiple fires were to break out there simultaneously, as in the Kobe event, many National Treasures would definitely be lost. The importance of cultural heritage disaster mitigation is recognized in 2003 by the national government and a National Committee was organized. The report of the committee discusses the importance of protecting both cultural assets and local regions, collaboration between local citizens, custodians of cultural assets, and government, and the types of measures required in the future. Complying with the Kyoto city's request, the national government approved funding for the first phase of the project in its budget request for fiscal 2006. This is the first national project for protecting cultural assets against natural disaster. The focus of the project is two 1,500-ton underground water storage tanks near Kiyomizu temple and San'nei-zaka area. Equipped with a pressurized water sprinkler system and other fire control facilities, not only will it be used to fight fires during big earthquakes, but as an easy-to-operate fire hydrants for other fires as well.

Keywords: *cultural heritage, post-earthquake fire*

1. A FORGOTTEN POINT OF VIEW

The Cultural Assets Preservation Act was established in 1950, one year after the Kondo Mural Painting at Horyuji Temple was destroyed by fire. Since then, thanks to continuous effort by the central and local government and the cultural heritage community, Japan has achieved significant and brilliant results in cultural heritage preservation. These wide-ranging results include the prevention and mitigation of age-induced changes to cultural heritage, the excavation and examination of buried cultural assets, and protecting cultural heritage from fire.

This is not to say, however, that there has been enough done in preparing for natural disaster. Many treasures have been lost due to natural disasters — for example the damage of the stage on the sea at Itsukushima Shinto Shrine during Typhoon No. 18 in September 2004, and the damage to the five-story pagoda at Murouji Temple from a fallen tree in September 1998.

The field of cultural property protection is wide and varied, with the problem of natural disaster alone having been overlooked. This lack of attention is particularly prevalent in measures for seismic hazard, as recognized by leading cultural properties protection expert Kakichi Suzuki, former director of the Nara National Research Institute for Cultural Properties (Fig. 1). Tamae Ohnishi, then-manager of the Traditional Culture Division in the Agency for Cultural Affairs, who was in charge of protecting the government's cultural properties, acknowledges that cultural property fire-prevention measures thus far, having focused on accidental fires and arson within the precincts of shrines and temples, have been ineffective in preventing fires from spreading to historical buildings during simultaneous outbreaks of fire in surrounding areas which are of concern during an earthquake. In other words, experts in the field of cultural property preservation recognize the need to focus on this problem in the future. Meanwhile, there are nearly two thousand researchers nationwide involved in preventing and mitigating natural disaster. But such researchers and technicians have not worked organizationally to tackle the problems inherent protecting cultural properties from disaster. While individual research, encouraged by an interest in scholarship, has been conducted on a small scale for historical buildings and other cultural assets, it has not been organized. That is to say, since cultural properties and assets are irreplaceable, they should be viewed from a different perspective than other assets of society. However, research in the area of natural disaster thus far has not been conducted from such an all-encompassing perspective.

Kakichi Suzuki, former director of the Nara National Research Institute for Cultural Properties: "Measures for coping with big fires caused by earthquakes have been completely lacking in policy for cultural assets preservation."

Tamae Ohnishi, then-manager of the Traditional Culture Division in the Agency for Cultural Affairs: "Protecting cultural properties from fires caused by earthquakes differs from the cultural property preservation policy that the national government has pursued thus far."

Figure 1 Problems in cultural heritage preservation

As shown in Figure 2, safeguarding against natural disaster has been neglected among cultural property preservationists. Similarly, people involved in natural disaster prevention or mitigation have neglected to treat cultural properties as something special. The problems involved in protecting cultural properties from disaster, then, have been overlooked in both cases. However, the way of rethinking of the problems of cultural heritage disaster prevention following the Great Hanshin-Awaji Earthquake (commonly referred to as the Kobe Earthquake) of 1995 has gradually been assimilated over a wide spectrum. This is because this formerly neglected issue has come to the attention of many people, including those of the cultural assets community, those involved in natural disaster prevention and mitigation, and people who are not directly involved in either of these areas. But now this new way of thinking is gradually coming to the fore.

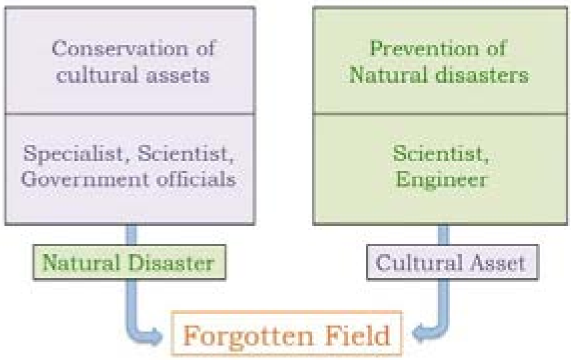

Figure 2 Protection of cultural heritage from natural disaster

2. SO, WHAT'S THE PROBLEM?

In the Great Hanshin-Awaji Earthquake of 1995 Kyoto was shaken by seismic intensity 5 , but damage was relatively slight. Thirty people were injured, and more than 1,000 homes were damaged, including those that received only slight damage. Also more than eighty shrines and temples were damaged, including cases of partial damage to earthen walls and other structures. All of that damage was slight. In some instances, such as at Ninnaji and Daigoji temples, the firefighting equipments were disrupted, precluding efforts to extinguish the flames. The resulting damage was as indicated in Figure 3.

□Firefighting equipment from the mountainside tank damaged by fire

□Firefighting equipment damaged by a strong earthquake

□What would happen if a big earthquake hit Kyoto?

Figure 3 Damage to temples in Kyoto during the 1995 Kobe earthquake

Kyoto is located some 50 or 60 km away from Kobe. If an earthquake were to strike closer to Kyoto, it is not hard to imagine that many more temples and shrines would be damaged. Though firefighting and fire-prevention equipment, including underground and mountain-based water tanks and fire cannons, are connected by underground pipes, most of those pipes are of low quake-resistance. While historic and important temples and shrines have been equipped with such facilities for many years, until the 1980s seismic effects on underground pipe lines had not been considered in seismic resistand design. As a result, historic temples and shrines have little protection from earthquakes. In addition to this lack of equipment and facilities to combat earthquake-induced fires, there is one more important inadequacy that must be pointed out.

So what is lacking in the existing facilities? As indicated in Figure 4, there is a shortage of reserve water. Since most firefighting facilities at temples and shrines are used to extinguish flames from accidental fires and arson within temple and shrine precincts, they only have enough water to fight the flames for the short period until the fire engines arrive or during the early stages of the fire. However, since multi-cites fires can be anticipated after strong earthquakes in big cities, chances are very slight that enough fire engines could be sent to a specific temple or shrine. Even if they were, they would probably not be able to get through, because the narrow streets would probably be blocked by fallen buildings and flames. Therefore, it must be assumed that fire engines would not come during and after an earthquake. This means, of course, that there are not enough water reserves, since they are set aside under the assumption that fire trucks will indeed show up. Without enough water reserves, fires in surrounding areas will not be prevented from spreading to the precincts of temples and shrines. (Fig. 5)

•Action taken by temple authorities to combat accidental fires and arson within precincts
spread of fire from outside the precinct of temple during an earthquake

•Shortage of reserve water
self-efforts to extinguish the flames until fire engines arrive

•Existing facilities and equipment are useless against earthquake-induced fires.

Figure 4 Problems with existing fire-prevention and fire fighting facilities and equipment

This inadequacy in facilities to combat fires must not be overlooked. Exacerbating such inadequacies is the problem of a lack of quake-resistance of water cannon pumps and power-generating equipment at temples and shrines. If any of these pieces of equipment are disrupted, even partially, they lose their overall capacity to combat fires. Nevertheless, thus far the quake-resistance of firefighting and fire-prevention facilities has rarely come under scrutiny. So while facilities and equipment used to protect cultural assets must be urgently inspected for quake-resistance and seismically strengthened, the biggest problem is that measures for containing the spread of fire are not even a topic of consideration.

Figure 5 Wooden residential buildings situated closely together in an area containing cultural assets

3. DANGER OF FIRE UP FIVE-FOLD SINCE THE TURN OF THE 20TH CENTURY

Kyoto has one of the lowest rates of fire outbreak among large cities in Japan. This is probably due to a visceral sense of potential danger among the citizenry of Kyoto, which contains many old wooden buildings — which, along with the city itself, were spared from the destruction of World War II. However, a low rate of fire outbreak and high resistance to fire are two different things. Since there are so many old buildings, if a fire were to break out, it would probably be very difficult to extinguish.

The areas of dense population in Kyoto of about 120 years ago (in 1887) (Figure 6)was about the same as they were at the time of the great fire of the Tenmei era (1788), during which 80% of the city was burned out(Fig. 7). According to an Ordnance Survey map, just one hundred years ago Kyoto's population lived between Higashiyama-dori and Senbon-dori streets, and Kitaohji-dori and Kyoto Station — while the rest of the city was farmland. Today the Kyoto basin is covered with residential buildings from every corner to corner, with the populated area expanding about fivefold in just a century.

Today there is not even one wooden building which is a National Treasure (Nijo Castle) in the area that burned during the Tenmei Great Fire. National Treasures in the areas which were not burned only survived because of the sparse scattering of houses in and around those areas. Since the densely populated Kyoto basin of today is covered with flammable materials, if multiple fires were to break out there simultaneously, as in the Great Hanshin-Awaji Earthquake of 1995, many National Treasures would definitely be lost.

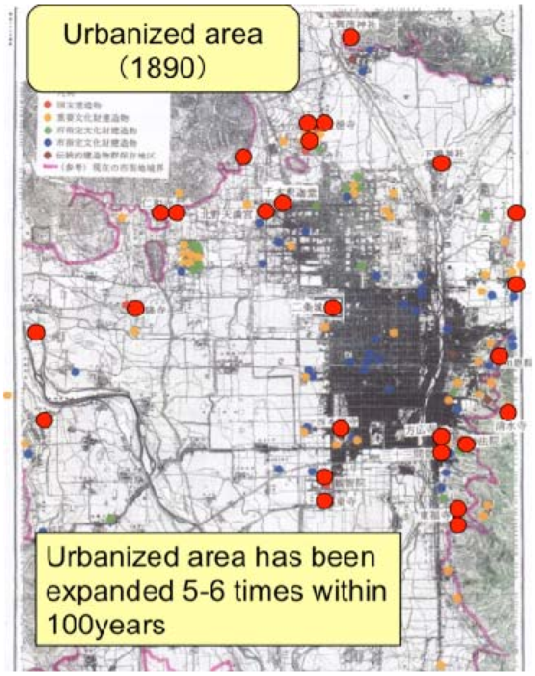

Figure 6 Areas of densely populated area in the middle of Meiji era
and location of National Treasure buildings

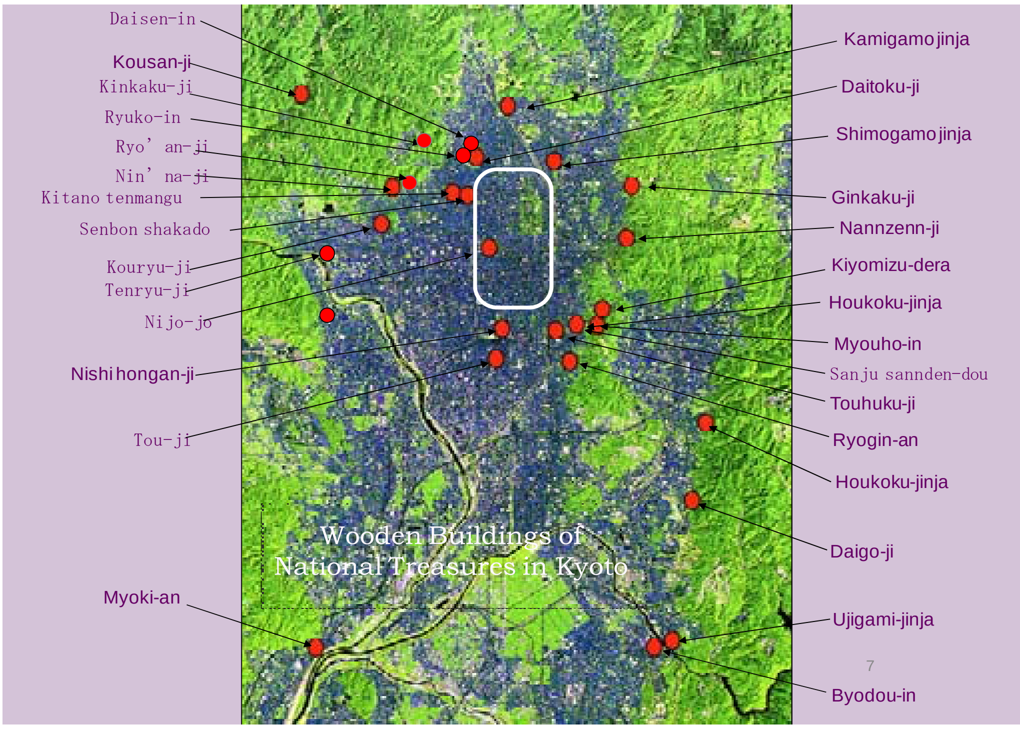

Figure 7 Existing cultural assets and area burned out by the Ten'mei Great Fire

Some people assume that if something burns down, it can be rebuilt. But such reconstruction entails extreme difficulty. The reason is that while many historical and cultural properties were privately owned by political leaders or the nobility, many of those that had been destroyed by fire were rebuilt or restored through donations by political and religious leaders. The reason that so many of Kyoto's rebuilt or restored historical buildings date back to around the turn of the 17th century is because that was a time when the leaders of the government held firm political power.

But such a degree of political power no longer exists in Japanat present tme. Nor are private individuals apt to donate funds to restore and rebuild historical buildings. What's more, the national government is not allowed to provide support to specific religious institutions. If many cultural properties were lost to fire, they would not be rebuilt as they were in the past. That this was a problem even in the modern age is clear from the fact that there are not many buildings currently designated or likely to be designated as National Treasures in the area destroyed by the Tenmei Great Fire.

4. KINKI REGION IN AN ACTIVE SEISMIC PERIOD

During the sixty years since WWII, Japan has caught up with and even surpassed Western societies in its drive for economic advancement, and since the Fukui Earthquake in 1948 and the Typhoon Isewan (Vera) in 1959, the country has not been hit by a natural disaster that would kill thousands of people. There were only two earthquakes of magnitude 6 or greater in the Kinki Region during the forty years between the Fukui and Great Hanshin-Awaji earthquakes. However, during the fifty years between 1900 and the Nankai Earthquake of 1949, there were more than thirteen earthquakes of a magnitude of 6 or greater in the Kinki Region alone (Fig. 8), with all of them coming during the short eighteen-year period between 1925 and 1943.

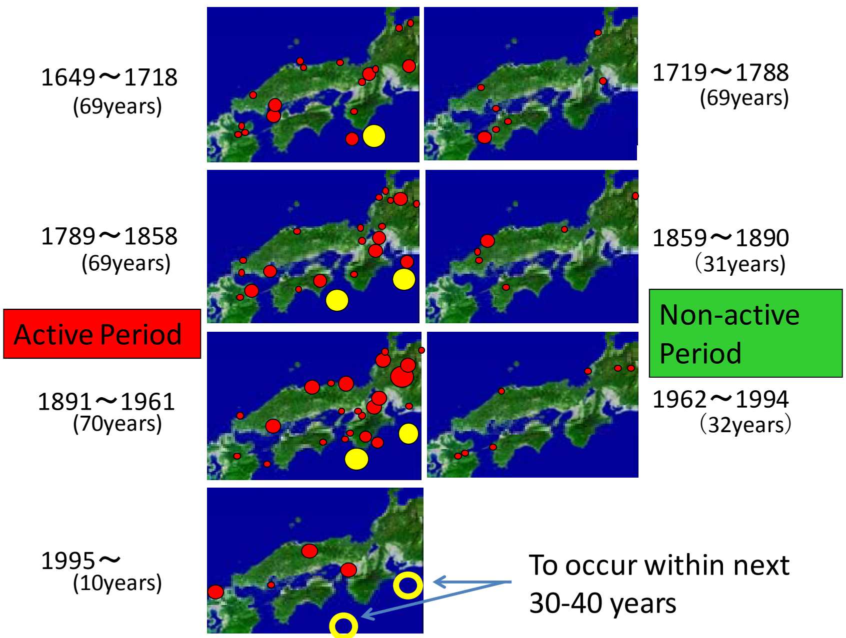

Figure 8 Many earthquakes occurred inland in the Kinki Region before the Tohnankai and Nankai earthquakes

In light of these facts, it would be a misunderstanding to think that there are not many earthquakes in the Kansai Region, as concluded during the fifty years since the end of the war. The entire seismic environment from the Kansai Region to the Tokai Region is a product of the Tokai, Tohnankai, and Nankai Earthquakes along the Nankai Trough. History clearly shows that these earthquakes recur over cycles of 100 to 120 years. (Fig. 9) Therefore, the earthquakes of these regions must be looked at not in terms of fifty years, but in terms of a hundred years.

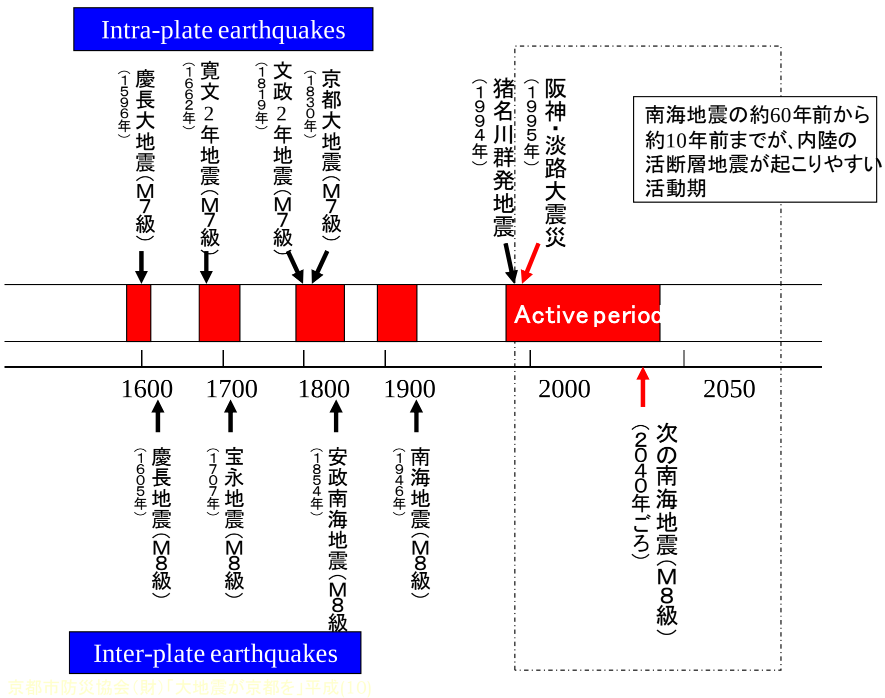

Figure 9 Earthquakes causing damage in Kyoto

From this point of view, it can be said that we are in an active period like the one that began in 1925, starting with the 1995 South Hyogo Prefecture (Kobe) Earthquake. It would seem that the Western Tottori Earthquake in 2000 and the Geiyo Earthquake in 2001 are part of a series of inland quakes. Though none of us hope for disaster, the fact is that an inland quake in the Kansai will definitely occur in the not-to-distant future. But since we do not know when it will be, we do not have a sense of imminent danger — and our desire for an earthquake not to occur somehow transforms into the notion that there will never be a quake in an area where we live. “I never thought an earthquake would strike where I live,” said a victim of the Mid Niigata Prefecture Earthquake in October 2004 in a televised interview. Most people would probably feel the same way. In the Great Hanshin-Awaji Earthquake more than six thousand people died. However, it is doubtful that anyone thought, “Tomorrow morning I might die in an earthquake.” But unlike then, currently the experts tell us that the Kansai is in an active seismic period. We must not look upon this problem unscientifically, based on wishful thinking.

5. EARTHQUAKE MEASURES ARE A KIND OF "LIFE INSURANCE" FOR KYOTO

Some 47 million tourists flock to Kyoto each year. Since they come to see the historic buildings and cultural properties at the temples and shrines (Fig. 10), the loss of these cultural assets would hurt Kyoto terribly, and the number of people who visit the city would drop drastically. One might say, then, that cultural properties and historical heritage are a kind of lifeline of Kyoto.

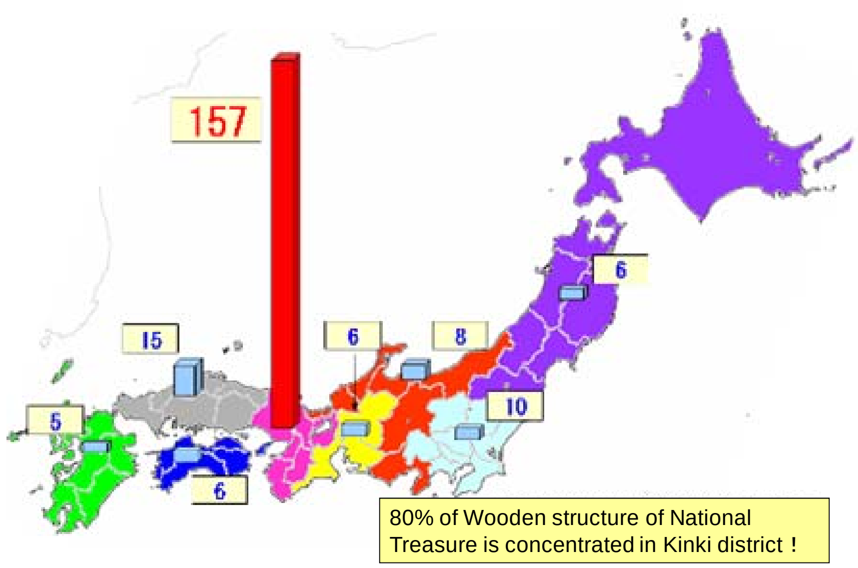

Figure 10 Concentration of wooden structure National Treasures in Kinki district

If cultural assets determine the fate of Kyoto, shouldn't it have an insurance policy to protect itself? Such insurance is to be found in disaster prevention measures. At the present time, however, Kyoto's cultural assets do not seem to be sufficiently insured. The reason we say this is because since firefighting equipments and facilities at temples and shrines are not sufficiently earthquake-resistant, in case of an earthquake those facilities would loose firefighting functions. The previously mentioned two famous temples in Kyoto were unable to fight fires after the quake in Kobe some 50 or 60 km away. If an earthquake were to strike Kyoto, then, most of its historical buildings would be devastated.

Also, as things currently stand, there is not enough reserve water to protect these buildings until fire trucks arrive. But in a big quake there would probably be multiple fires breaking out simultaneously, and fire trucks would be unable to get to the scene through the narrow and burning streets. What's more, Kyoto has more than twice as many pre-WWII wooden buildings than does Kobe. In light of these facts, it is not hard to imagine that if a big earthquake were to hit Kyoto or its vicinity, many cultural assets would be burned out by fire.

Considering the degree of potential danger, certainly everyone would agree that measures against disaster, particularly earthquake-induced fire, must be urgently implemented as a form of insurance. We wonder, then, why such measures have not been put in place. Most adults have life insurance. However, the reason people do not become seriously involved in countermeasures against disaster — i.e., life insurance policies for the cities and towns in which they live — must be because they are concerned about the non-collectable nature of such insurance. But certainly nobody wants to collect on life insurance. Even if disaster measures are put in place as insurance, it doesn’t mean that there will necessarily be a big earthquake in Kyoto that will destroy many of its cultural assets. If people do not worry about the fact that they can never collect on their life insurance policies, there should be no problem if all types of insurance were made to be non-collectable.

Cultural properties contain the cultural remnants of the mentality of people of past ages. Through cultural properties we can learn about that mentality. Since culture itself is and invisible, without cultural properties it would be impossible to get a glimpse of the hearts and minds of people of ages past. Thanks to the wealth of information from past ages contained in cultural properties, these objects help us learn about our history, particularly mental activities. It is for this very reason that we, who are alive today, must make every effort to preserve cultural heritages for future generations.

But one wonders if we truly make the same effort to hand down cultural assets to future generations as we do in the pursuit of the everyday comforts of modern civilization. During the sixty years since the end of WWII we have pursued economic prosperity and material comfort. Now that we have achieved a relatively high degree of comfort, isn’t it time that we start thinking about future generations?

6. WHAT MUST BE DONE NOW

The importance of cultural heritage disaster mitigation is recognized by the national government and some local governments. As indicated in Figure 11, for example, in June 2003, the Cabinet Office established an Inspection Committee to Protect Cultural Assets and Local Regions from Natural Disaster, and in July 2004 it issued a report on “Measures Needed to Protect Cultural Assets and Local Regions from Seismic Hazard.” (Fig. 12) This committee is made up of academic experts, with relevant government agencies acting as offices of the committee. The report discusses the importance of protecting both cultural assets and local regions, collaboration between local citizens, custodians of cultural assets, and government, and the types of measures required in the future.

It also presents the case studies on the areas around Kiyomizu Temple and San’nei-zaka in Kyoto, and on the Shibamata Taishakuten area in Tokyo. There is a separate page appended to the end of the report, which begins with the words “Relevant government agencies.” This could be interpreted as demonstrating a kind of national will to prevent cultural assets from disaster. This page also says that relevant government agencies will collaborate to raise the level of importance placed on cultural assets in efforts to prevent disaster in local areas, helping to implement those projects in the near future.

Inspection Committee to Protect Cultural Heritage and Local Regions from Natural Disaster

Central Disaster Prevention Council
(Cabinet Office, organized in June 27, 2003)

◇Academic experts on the committee
15 experts and Chairperson

◇Committee members representing the government and public sectors
Disaster-prevention specialist from the Cabinet Office
Fire and Disaster Management Agency
Agency for Cultural Affairs, Ministry of Education, Culture, Sports, Science and Technology
Ministry of Land, Infrastructure, Transport and Tourism
Local public agencies (Tokyo Metropolitan Government, Kyoto City)

Figure 11 Committee organization

Measures Needed to Protect Cultural Heritage and Local Regions from Seismic Hazard

Chapter 1: Background of Plan
Chapter 2: Basic Views in Protecting Cultural Heritage and Local Regions from Seismic Hazard
Chapter 3: Basic Views in Protecting Cultural Heritage and Local Regions from Seismic Hazard
Chapter 4: Specific Measures
Chapter 5: Tasks in Realizing These Measures

Relevant government agencies will pursue the following toward protecting cultural heritage and local regions from seismic hazard:

1.Raise the level of importance placed on cultural heritage disaster mitigation measures, as part of a disaster-mitigation project
2. Support local regions in realizing these objectives.

Figure 12 Contents of report

Thus, relevant government agencies at least recognize the importance of cultural heritage disaster prevention measures. The city of Kyoto, with its wealth of cultural properties, has for the past several years expressed concern over these issues. Determined to maintain its historical ambience, the city has set up a committee to find a way to create a water supply system for use in disaster prevention efforts. Meanwhile, The Society for Protecting Cultural Assets from Disaster, an NPO, has been active for thirteen or fourteen years, though formerly as a different organization. The society has conducted case studies for the above-mentioned committee. In addition, at the request of the national government, the society, Kiyomizu Temple and local citizens have collaborated to formulate specific disaster prevention measures for Kiyomizu Temple, Sanneizaka, and the surrounding area. As the local government, Kyoto City is also involved. After the plan was completed in March 2005, it was established as an official plan of Kyoto City and submitted to the national government. Thus, the implementation of cultural heritage disaster mitigation measures requires not only the cooperation of custodians of cultural properties, but also a specific plan that is acceptable to local citizens.

The current activities in the vicinity of Kiyomizu Temple consist of a pilot project, and the similar methods and procedures will most likely be required to realize disaster mitigation measures in a specific area focusing on cultural assets. Since formulating such a plan requires specialized knowledge, including technical expertise, it is no small task for this NPO, which consists of volunteers and experts from various fields. At any rate, since it is important to form a rational and effective plan which will be acceptable to the temples and shrines housing the cultural assets, as well as to the local citizens, efforts have been urgently initiated to find the optimum means for realizing such a plan. However, there is not a whole lot of time left before the next earthquake will strike. (Fig. 13)

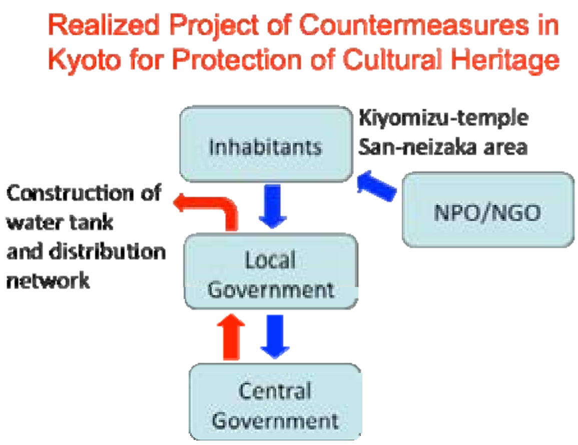

Figure 13 Cycle of collaboration

7. THE WORK HAS BEGUN

While paying due attention to historical ambience, the Society for Protecting Cultural Assets from Disaster has also explored the particulars of a water supply system for use in disaster mitigation efforts. In order to arrive at a viable system and implement it, the society has been talking with Kiyomizu Temple and local citizens, realizing the necessity of not only knowing the geographical features of the area but also forming a relationship with the temple and the local citizenry.

That is to say, the NPO has formed a Study Group for Maintaining a Disaster Mitigation Water Supply System, and crafted a plan thereof, with the cooperation of Kiyomizu Temple, Kodaiji Temple, representatives from local governments, and the Kyoto City Fire Department. It also held a workshop in supplying water for environmental disaster mitigation, involving people from the city government and others. After more detailed study, it was decided that further technical investigation was required. The NPO, then, obtained small amount of financial assistance from the national government in its collaborative efforts, playing a certain role in administrative actions.

The resulting proposal was to dig a tunnel (to avoid blemishing the landscape) through the mountains of Higashiyama for storing water (Fig. 14); and to install fire hydrants and a water sprinkler system in the area bounded on the east and west by Higashioji Road and Higashiyama, and on the north and south by Maruyama Park and Otani Honbyo (Otani Mausoleum). One of the proposed water sprinkler systems is equipped with "mist defense" (Fig. 15) that envelops endangered buildings and facilities with a protective mist.

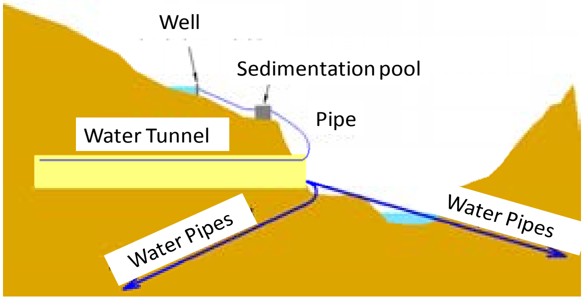

Figure 14 Water storage tunnel in Higashiyama


Figure 15 Mist defense system in action

After the concrete proposal was presented to Kyoto City, it was slightly revised, and in June 2005, the mayor asked the national government to prepare a budget for the project. Complying with the city's request, the national government, in turn, approved funding for the first phase of the project in its budget request for fiscal 2006. This is the first national project for protecting cultural assets tank against natural disaster. The focus of the project is a 1,500-ton underground water storage tank beneath the "disaster-prevention park" adjacent to the parking lot at Kodaiji Temple. Equipped with a pressurized water sprinkler system and other fire control facilities, not only will it be used to fight fires during big earthquakes, but as an easy-to-operate fire hydrants for other fires as well.

The construction work of underground water tank was completed in January 2007. (Fig. 16) Still in its initial phase, the project seems very promising as it moves forward, and must be further developed to include not only Kiyomizu Temple but areas containing historical assets nationwide. The current project for protection of cultural heritages from earthquake fire (Fig.17) will be completed in March 2011.

At the present time (2010), two tanks colored in light blue have been constructed and underground trunk pipe line by polyethylene pipe was buid up. Water in this system are used for ordinary fire in the vicinity of the area through hydrant by fire engines and also inhabitants of the area can use water for daily purpose to sprinkle on nearby streets by making use of ordinary hand pump. Namely, this system is designed as a multipurpose usage, not only for fire after earthquake.

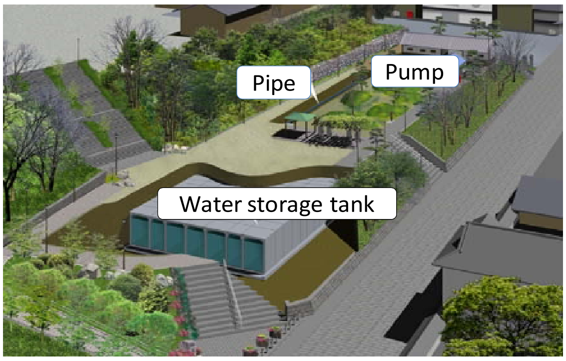

Figure 16 Water storage tank in the “disaster-prevention park” at Kodaiji Temple (completed in January, 2007)

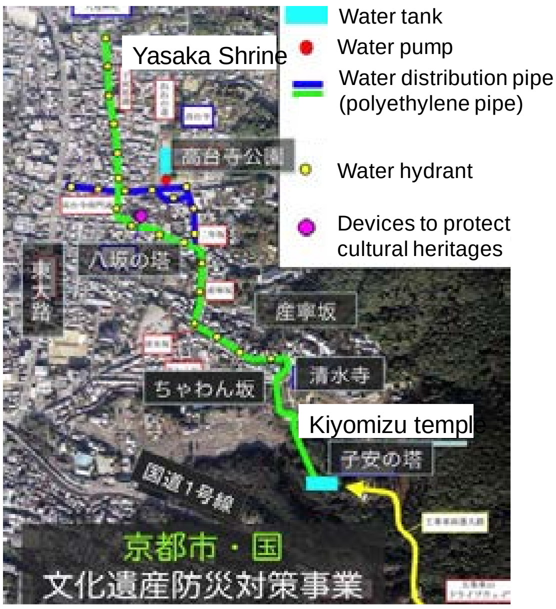

Figure 17 Project for protection of cultural heritage from post-earthquake fire

REFERENCE

Kenzo TOKI: Cultural Heritage and Seismic Countermeasures, “Introductory Volume” to Cultural Heritage Disaster Mitigation Studies, Ritsumeikan University, 2010.

How long can we use concrete structures?

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ABSTRACT

To maintain the human society, the civil structures are one of the most important and fundamental structures for the people to live in safety and in comfortable manner. Although a large number of civil structures are built elsewhere throughout the country, it is expected to use these structures for more than 100 years. Deterioration of these structures become obvious may be after 10 to 20 years after the construction. Deterioration is an inevitable phenomenon even when the structures are carefully made and used. This paper describes how the deterioration affects the safety of these structures, especially concrete structures, and explains how we should treat the structures to prevent further deterioration although their lives.

Keywords: *civil infrastructure, deterioration, maintenance*

1. INTRODUCTION

Japan experienced a rapid economic growth in the period of 1960 to 1980. More than 100 million cubic meters of concrete were used to construct the structures such as buildings, bridges, tunnels, dams, etc. to support the activities of Japanese people. As a result, large stock of these infrastructures is reaching 50 years of service, and due to deterioration of the structures, maintenance of these structures has become a major interest among the owners and the civil engineers.

On the other hand, population of Japan will reduce from now on because of fewer babies in a family (approximately 1.2 children per family) than needed to sustain the present population. Although high technologies have been developed in recent years, it is sure that fewer engineers will have to take care of this huge amount of structures from now on, which has never experienced in the past. Due to reduction in the economical growth, the budget for both construction and maintenance will be reduced in the future.

The maintenance of existing structures must be done with the following conditions: 1) rapidly increasing amount of existing structures reaching the age of 50 years, 2) less amount of engineers to maintain the structures, 3) less amount of budget to maintain the structures. Although there are many hazards in each country, concrete structures are expected to be safe for long period of time. If the structure is deteriorated before the hazards, the structure may easily collapse and it would be difficult to maintain the safety of the people.

In order to keep the safety of urban area, it is important to study and investigate not only on hazards but also on durability aspects of existing structures. Even a small amount of concrete spalling may cause large scale traffic accidents as we experienced in Sanyo-Shinkansen in 1999.

Considering these situations now, this paper explains what is happening now in Japan and how we are dealing with the problems through research and engineering.

2. GENERAL MAINTENANCE METHODS USED UNTIL NOW

The maintenance of concrete structures has been done mostly by the owners of the structures. In case of public structures, the ministries, etc. maintain the structure after the structures are completed. For the time being, the methods for the maintenance differ according to the owners of the structures. Although there are some differences, the main concept of the maintenance can be summarized as follows (Uomoto and Misra, 2001):

1. Periodic inspection and evaluation of deterioration degree
2. Detailed inspection and decision making
3. Repairing and strengthening of deteriorated structures

For periodic inspections, the inspectors inspect the structures visually, sometimes with the help of binoculars and hammers, once a year or once in several years according to the importance and time after the structure is completed. The inspectors are mostly trained engineers with experiences. The detailed inspection is done when the estimated degree of deterioration exceeds certain limit, or when some new phenomenon is found during the periodic inspection. The detailed inspection is done by visual inspections with the aid of non-destructive tests or taking core samples out from the inspected structure. The purpose of the inspection is to decide the cause of the deterioration and also to evaluate whether repair and/or strengthening is needed or not.

To repair or strengthen the existing structures, it is important to design and select sufficient methods and materials. The most popular repair method for corrosion of steel bars due to carbonation is to eliminate the carbonated concrete and replace it by new concrete and apply coatings with and without FRP sheets. But in case of steel corrosion due to chlorides from the surrounding environment, the high chloride concentration portions of concrete are taken out, anti-corrosive treatment is applied to the surface of the bar, and polymer cement mortar is generally used to repair the concrete before coating the concrete surface.

3. MAINTENANCE METHODS BY JSCE

The methods used in the new Standard Specification of JSCE are basically the same as the conventional method. The differences are that the new method requires maintaining the structure within their required performances throughout their service life.

Firstly, the listed below issues have to be clearly specified.

1) To maintain a structure, performances required for the structure must be clearly defined.

2) The performances required for general structures are “safety”, “serviceability”, “hazards to the public”, “aesthetics and landscape” and “durability”.

And the basic principles of maintenance works are as follows:

1) Structures must be maintained according to a designated maintenance category by formulating a maintenance program to retain the performance within the specified tolerances throughout their service life. And maintenance system includes adequate “initial inspection”, “deterioration prediction”, “inspection”, “assessment/judgment”, “remedial action”, and “record”.

2) To maintain a structure, in addition to the assessment and evaluation at the time of inspection, assessment and evaluation must be made throughout the service life of the structure based on prediction of deterioration.

3) To predict the deterioration, required performances of the structure must be clearly defined, and also the design service life must be made clear.

4) The records on design, construction, initial inspection, deterioration prediction, periodical inspection, assessment and/or evaluation, and remedial actions must be kept throughout the service life.

Standards for maintenance of concrete structure deteriorated by different mechanisms are also discussed. The lists below are the standard maintenance method published in this standard:

1. Carbonation induced deterioration
2. Chloride induced deterioration
3. Frost attack
4. Chemical attack
5. Alkali aggregate reaction
6. Fatigue of RC slabs and beams

In detail, for an example, the standard method for chloride induced deterioration recommends the model to predict chloride ion diffusion, progress of steel corrosion, and correction of the prediction. Also the methods of initial inspection, routine inspection, periodic inspection, and detailed inspection as well evaluation and judgment method are also discussed. Finally, for recommendation remedial measures, information on measurements of both repair and strengthening also have to be recorded.

One of the difficulties is how to predict the degree of deterioration at the end of their service life. There are several researches being done to predict the deterioration in numerical manner. In the published Standard, several numerical prediction methods are introduced as references for structures suffering cyclic fatigue loads, carbonation induced corrosion and chloride induced corrosion. In case of cyclic fatigue, S-N curves are used to predict the service life. In case of carbonation induced and chloride induced corrosion of steel bars, diffusion equations for carbon dioxide and chloride are used to predict the degree of corrosion. Using these prediction methods, deterioration degree can be estimated to certain degree. (See Figure 1) But for other deterioration problems, which has not been studied numerically, a quantitative model has not been proposed yet. To deal with the problem, a qualitative method, namely “Grading method”, is introduced in the Standard.

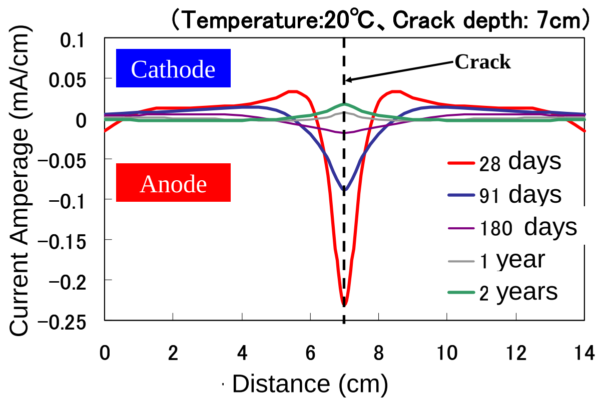

Figure 1: Quantitative prediction of corrosion in marine environment with cracks (Tsukahara et al., 2000)

4. PROBLEMS IN ACTUAL EXISTING STRUCTURES

When a civil engineer is asked by the owner to check the safety of an old existing structure, one of the largest problems is that there are neither drawings nor construction records of the structure available. No problem may occur in case of important facilities, which is maintained with great care. But in case of normal structures, the owners do not know the importance of these documents.

To deal with the problem, NDI is not enough. Fortunately, our structures are not too old, and they are mostly designed and constructed by the method specified by JSCE, AIJ or other associations. Considering these, the only way is to re-design the structure again using the methodologies used at the time of construction. Figure 2 shows an example of re-designed bridge pier constructed about 35 years ago. From the figure, it is much easier for a civil engineer to check the safety of the structure under several hazards. It will become more important for the owners and engineers to keep these documents throughout the service life of a structure.

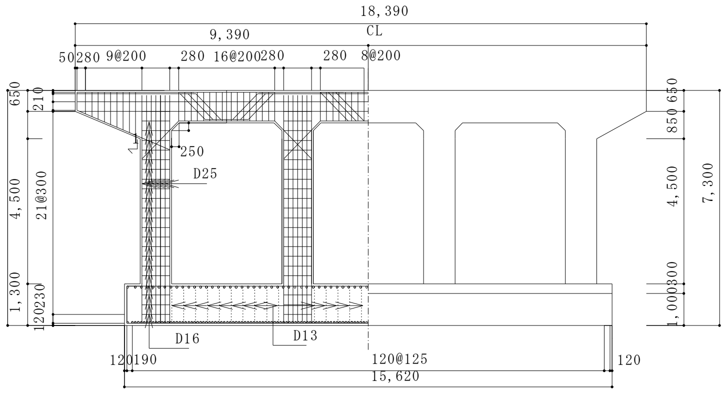

Figure 2: Re-designed reinforced concrete pier of a bridge (Okazaki, 2005)

If the re-designed structure is correct, we can easily estimate the service life of the structure using deterioration model considering the present deterioration degree of the structure. As mentioned in the JSCE Standard Specification, we can check whether the deterioration of the present structure is within estimated range or not. By modifying the estimation model, we can estimate the life of the structure more accurately.

5. NON-DESTRUCTIVE INSPECTIONS

New NDI Technologies are developed by many researchers and engineers. Although it is believed that NDT is the most powerful technology to check the safety of a structure, it is not so easy to utilize them. Some says if we monitor the structure by NDI, 1) we can easily get accurate information of the structure easily, 2) we can easily estimate when the structure may collapse by NDI, etc. To obtain useful results, we must know how we can get the important information. I would like to introduce some examples related to NDI.

5.1 Tunnel Lining Inspection

An example of the inspected result of a concrete tunnel lining is shown in Figure 3. As shown in the figure the cracks are observed elsewhere and the cracks are concentrated especially from S10 to S11. Most of these cracks are vertical to the tunnel axis, indicating that the cracks may be made by force rather than deterioration such as corrosion or alkali aggregate reaction.

After the construction, the tunnel has been used for 30years and quite a large amount of settlement was observed. Every year, the height of the tunnel is measured. Figure 4 shows the height and settlement of the tunnel just after the construction and after 30 years. As shown in the figure, the largest settlement was observed in the span No. S 13, and another portion was in the span No. 69. On the contrary, a large rise was observed in the span No. 43. These figure shows that the tunnel has moved downwards in some places, but also some portion moved upwards after the construction.

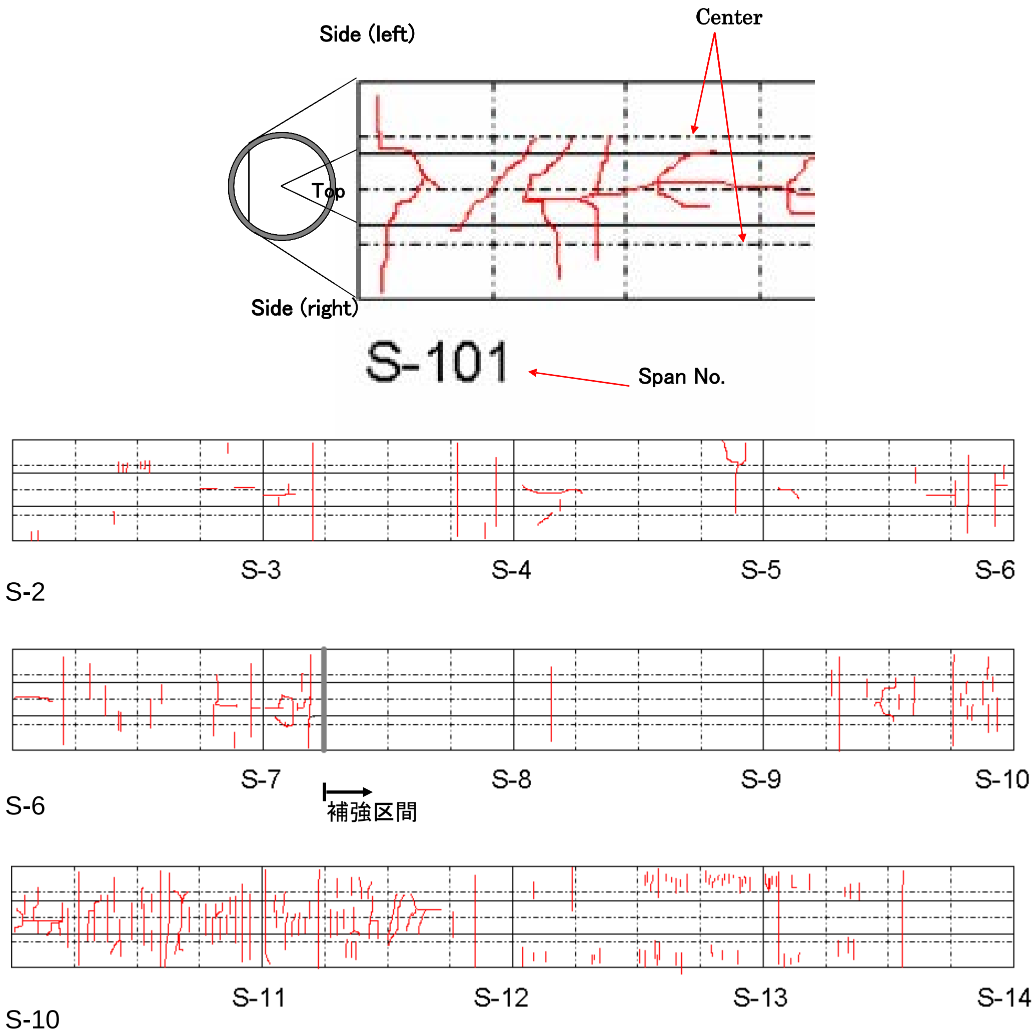

Figure 3: Crack distribution of a concrete tunnel from Span S2 to S14
(Takeuchi and Suzuki, 2007)

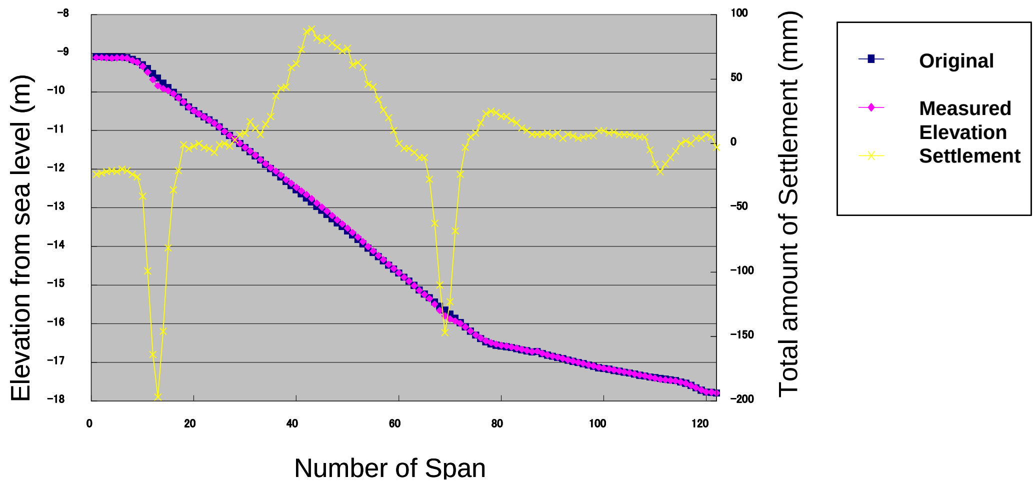

Figure 4: Level of the tunnel and amount of settlement measured after 30 years
(Takeuchi and Suzuki, 2007)

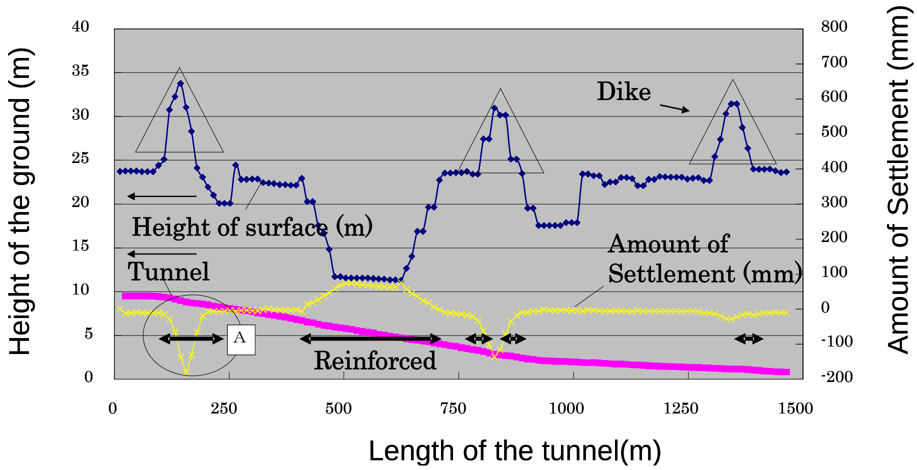

Figure 5: Comparison of the tunnel and the structures on the ground surface (Takeuchi and Suzuki, 2007)

These results indicate that the tunnel was affected by the structures constructed above the tunnel. When dikes are newly constructed, the tunnel sunk down with the movement of the ground and when the load above the tunnel reduces, the tunnel rise upward as in the case of the pond excavated after.

Comparing the measured height with the structures above, we can easily find that the tunnel just underneath the dikes has large amount of settlement and the tunnel below the pond has the rise as mentioned in the Figure 5.

5.2 Continuous Monitoring of a Structure

In case of an important structure, continuous monitoring may be needed to keep the structure safe. One of the problems is that it is difficult to monitor all the members of a structure continuously, considering the expense. How should we select the member to inspect is a big problem. The following example shows an answer to select the member in case of a truss bridge.

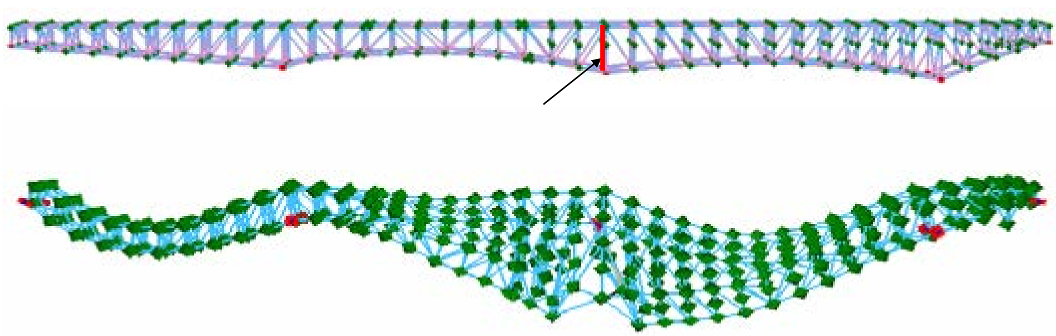

Figure 6: Estimation of the movement of a steel truss bridge when a member is deteriorated (Yazuawa, 2007)

The figure 6 shows how the steel bridge behaves if a member of the steel truss bridge is deteriorated. The calculation is done by 3 dimensional analysis, checking all the members what may happen if the member is deteriorated and can not support the load. As can be seen from the figure, the vertical member at the point of support is very important to maintain the bridge safe enough for the people to go across.

Knowing the evidence, we can monitor the bridge at this point. May be strain measurement is enough to check the safety of this bridge. Further, if we wish to monitor the structure as a whole, several points may be enough for the monitoring. We can reduce the cost to maintain and monitor the structure not to cause catastrophic failure.

6. CONCLUDING REMARKS

Engineering is not always complete, and further research works are needed. To sustain existing structures, durability of the structure is important. One good method is to construct durable structures, but for the existing structures, maintenance is the only way to deal with the problem. Although concrete committee of JSCE has set up a good system for maintenance of existing concrete structures, there are still many things to be done: not only researches but also education to the students and engineers about durability and maintenance. I hope this paper may become a help to the concrete engineers of the world who are trying to design, construct and maintain concrete structures.

REFERENCES

Concrete Committee of JSCE, *Standard Specifications for Concrete Structures-2007 "Design"*. JSCE, Tokyo.

Concrete Committee of JSCE, *Standard Specifications for Concrete Structures-2007 "Materials and Construction"*. JSCE, Tokyo.

Concrete Committee of JSCE, *Standard Specifications for Concrete Structures-2007 "Maintenance"*. JSCE, Tokyo.

Tsukahara, E., Koyama, R., Hoshino, T., and Uomoto T., 2000. Estimation Method of Corroded Portion of Reinforcing Steel Bar by Natural Potential Measurement. *Non-destructive Testing in Civil Engineering 2000*, Elsevier.

Okazaki, S., 2005. *Development of monitoring system for RC bridge based on restoration design method*. Thesis submitted to the University of Tokyo for Master of Engineering degree.

S. Suzuki, K. Kinoshita and T. Uomoto: Fundamental study on crack distribution and settlement of Shield Tunnel Lining, JSCE General Meeting of Kanto-shibu, 2008

M. Takeuchi, Y.S hirane and T. Uomoto: Fundamental study on relation between crack and surface load on Tunnel Lining, JSCE General Meeting of Kanto-shibu, 2008

S. Yasuzawa and T. Uomoto: Estimation of dangerous points of an existing steel truss bridge, JSCE General Meeting of Kanto-shibu, 2008

Application of Cement Stabilization Methods to Earthquake Disaster Mitigation

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ABSTRACT

In Japan, soft alluvial clay ground has frequently encountered in on land and marine constructions. The ground is so soft and compressible that large settlement and failure can take place. Sandy soil has relatively better properties for compressibility, but liquefaction might happen during earthquake in a case of loose and saturated condition. In fact, port and harbor facilities at Kobe Port were heavily damaged in the Hyogoken-Nambu earthquake in 1995, where gravity type of sea revetments displaced a couple of meters toward sea together with large ground settlement at backfill yard. There are many kinds of soil stabilization techniques developed and available in Japan for countermeasure of stability, ground deformation and liquefaction. Among these techniques, cement stabilization techniques have been also frequently applied to improvement of clayey and sandy soils. In this paper, some applications of three cement stabilization techniques to earthquake disaster mitigation are briefly introduced.

Keywords: cement stabilization technique, liquefaction, disaster mitigation

1. INTRODUCTION

In Japan, soft alluvial clay ground has frequently encountered in on land and marine constructions. The ground is so soft and compressible that large settlement and failure can take place. Sandy soil has relatively better properties for compressibility, but liquefaction might happen during earthquake in a case of loose and saturated condition. In fact, port and harbor facilities at Kobe Port were heavily damaged in the Hyogoken-Nambu earthquake in 1995, where gravity type of sea revetments displaced a couple of meters toward sea together with large ground settlement at backfill yard. Table 1 shows the amount of damage to port facilities caused by strong earthquake (Noda, 1991), and demonstrates quite large difference between with and without liquefaction. According to the table, the amount of damage when liquefaction takes place is about 20 to 50 times greater than that without liquefaction. This highlights the importance of liquefaction mitigation to minimize earthquake disasters.

There are many kinds of soil stabilization techniques developed and available in Japan for countermeasure of stability, ground deformation and liquefaction. Among these techniques, cement stabilization techniques have been also frequently applied to improvement of clayey and sandy soils. In this paper, some applications of stabilization techniques, Deep Mixing Method, Premixing Method and Lightweight Treated Soil Method, to earthquake disaster mitigation are briefly introduced.

Table 1 Comparison of amount of damage

Earth-quake	Magnitude	Port	Soil type	Max. accel. (gal)	Lique-faction	Damage (million yen)
Niigata, 1964	7.9	Hachiohe	Sand	233	No	1,980*
Tokachi Oki, 1968	7.5	Niigata	Sand	159	yes	49,700*
Miyagiken Oki, 1978	7.4	Shiogama	Clay	273	No	160*
	7.4	Ishinomaki	Sand	195-210	Yes	3,008*
Urakawa Oki, 1982	7.3	Muroran	Sand	164	No	120
Nihonkai Chubu, 1983	7.7	Akita	Sand	205	Yes	6,400

* converted into 1978 prices.

2. DEEP MIXING METHOD

2.1 Outline of the method

Deep Mixing Method (DMM), an in-situ admixture stabilization technique using cement and/or lime as a binder, has been applied in many construction projects for various improvement purposes (CDIT, 2002). DMM was put into practice in Japan in the middle of 1970s to improve soft marine deposits, then spread into China, South East Asia, and recently to the other part of the world. Two decades

(a) for on land construction

(a) for marine construction
Figure 1: DM machine

of practice have made equipment improved, binders changed, and applications diversified. Lime is replaced with cement in Japan. Figure 1(a) and 1(b) show a DM machine for on land and marine constructions. The special machines used to stabilize soft soil are basically composed of several mixing shafts and blades, and a binder-supplying system. In one operation, a column of treated soil is constructed in a ground. Through a series of construction steps, any arbitrary shape of improved mass (such as block, wall and grid types) can be formed in the ground. For liquefaction mitigation, the block and grid types of DMM have been applied.

2.2 Applications to earthquake disaster mitigation

Figure 2 shows an application at Kushiro port for liquefaction mitigation of backfill, where sandy ground was stabilized by a block type improvement with 100% improvement area ratio, the ratio of the improved soil area to the whole site area. The design field strength, q_u, was 100 kPa, which was considerably low level compared with that for clay soil improvement. The revetment was subjected to the Toho-Oki earthquake in 1994, which caused huge damages with liquefaction and cracks at unimproved area. However, due to the ground improvement, negligible damage took place at the revetment, which has confirmed the high applicability of DMM for earthquake disaster mitigation.

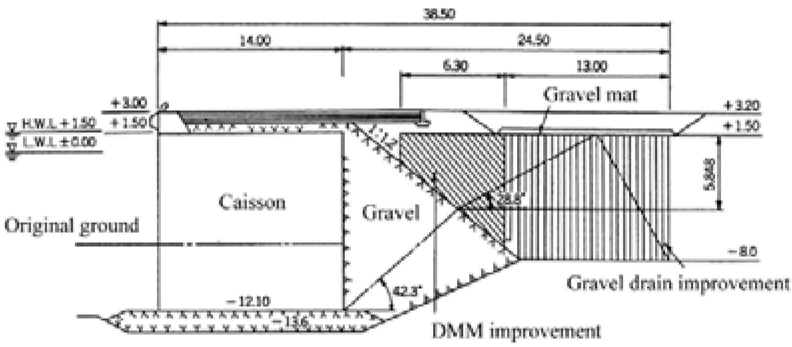


Figure 2: Application of DMM at Kushiro port

DMM was applied to foundation of a building at Kobe port, where sandy ground was improved by a grid type improvement to prevent excess pore water pressure generation during earthquake. A 14-story building located on Meriken Wharf in Kobe was experienced the Hyogoken-Nambu earthquake in 1995. The soil profile at the site consisted of 10 - 12 m of soft reclaimed sand and gravel layers over the seabed. The seabed soil consisted of alternating layers of clay, sand and gravel. The building was supported by cast-in-place reinforced concrete piles with a diameter of 2.5 m extending to dense diluvial sand and gravel at a depth of 33 m. Its section and plan diagrams are shown in Fig. 3. A grid type improvement was applied to prevent liquefaction in the upper loose fill. The improvement area ratio was approximately 20 %. The unconfined compressive strength of the improved soil after about six weeks curing was 4 - 6 MPa (Suzuki et al., 1996; Namikawa et al., 2007).

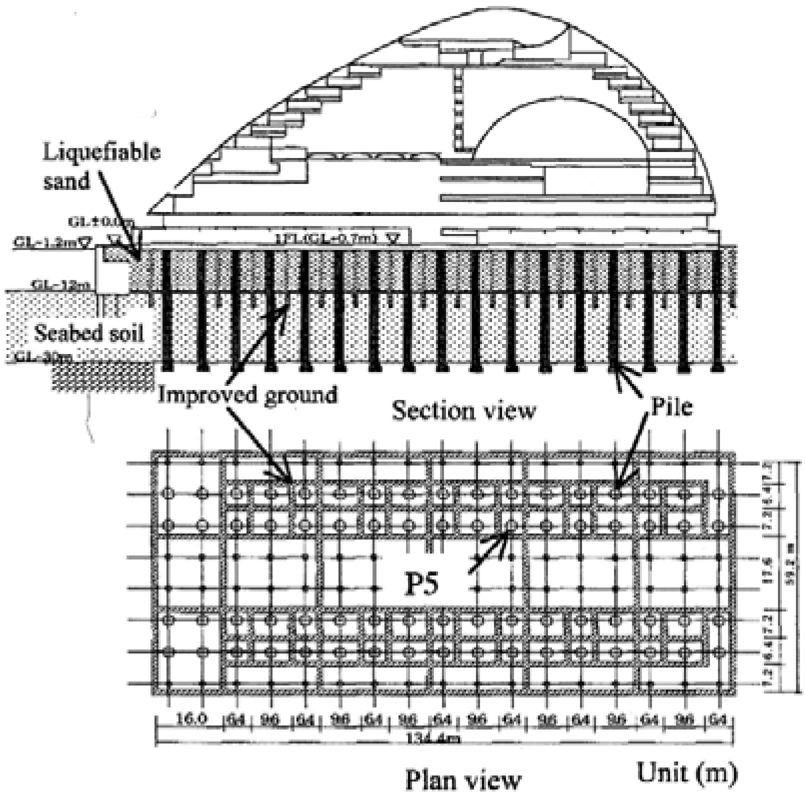


Figure 3: Application of DMM at Kobe port

Figure 4(a) shows the damage of quay wall near the building after the earthquake. The concrete caisson type quay walls on the west, south and east displaced horizontally by 1 m, 2 m, and 0.6 m respectively and settled by 0.5 m, 0.6 m and 0.3 m. Sand boils and ground fissures were observed at the ground surface. In the building, however, there was no crack at the surface of the improved ground as shown in Fig. 4(b). The head of the cast-in-place piles supporting the building was found to be intact. Moreover, negligible differential settlement was observed on the first floor of the building. These have indicated that the cement stabilization improvement could mitigate the damage to pile foundation and superstructure.

(a) sea revetment near the building

(b) parking area in the building
Figure 4: Damage due to the earthquake

3. PREMIXING METHOD

3.1 Outline of the method

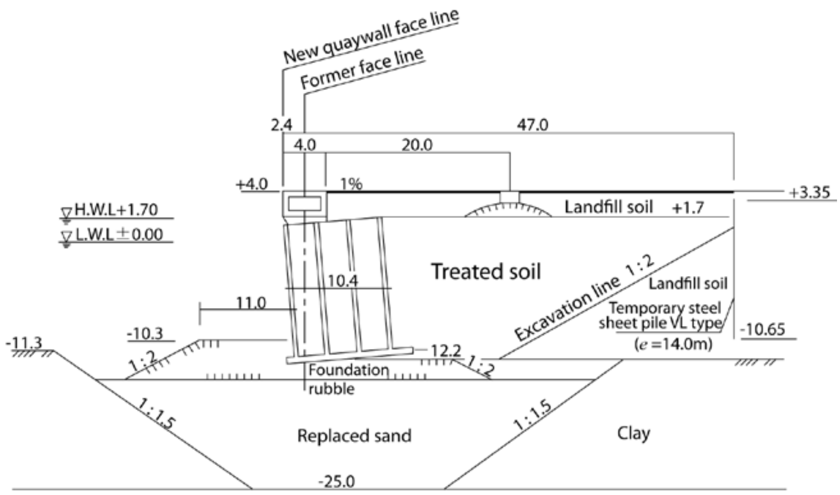
Premixing Method has been developed for liquefaction mitigation where a small amount of binder and a chemical additive are mixed with sandy materials (CDIT, 2003). Recently, it has been also frequently applied for reducing the earth pressure acting on the revetment, backfilling behind sheet walls and concrete caisson, and land reclamation material. After mixing these materials in a mixing plant at field, the stabilized soil is transported and placed at a designated area to construct a stabilized reclaimed ground (Zen et al., 1990). Conventional liquefaction remediation techniques have been generally applied to existing sandy ground. This method, however, has been applied to fill material which is anticipated to liquefy. The basic principle of the method is that the shear strength of stabilized soil does not decrease to zero and liquefaction does not take place even if the pore water pressure is generated up to the overburden pressure at site.

In the execution, sandy soil is mixed with binder and separation inhibitor and then placed at site, where belt conveyor mixing with dumper chutes and mechanical mixing by screw type mixer are available. In placement of stabilized soil, spreading, chute and direct placement methods are available.

Figure 5: Premixing Method

3.2 Application to earthquake disaster mitigation

Figures 6(a) and 6(b) show an application at Kobe port where a concrete type quay wall was damaged in the Hyogoken-Nambu earthquake, in which the concrete caisson displaced horizontally and titled. As the amount of displacements were within the allowable values, the caisson was used without re-positioning but the backfill was excavated and replaced by the stabilized soil in order to reduce the static and dynamic earth pressures acting on the caisson. The design strength of the stabilized soil was 100 kPa and blast furnace cement type B of 7.5 % in stabilized ratio was mixed with the soil as well as separation inhibitor agent of 75 mg per unite dry weight of sand to achieve the design strength.



(a) section view

(b) execution of improvement at site
Figure 6: Application of Premixing Method at Kobe port

4. LIGHTWEIGHT TREATED SOIL METHOD

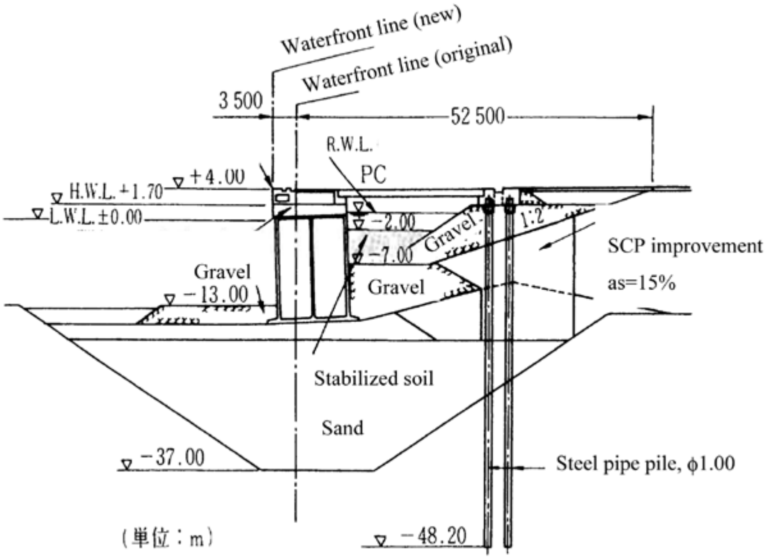
4.1 Outline of the method

Lightweight Treated Soil Method was developed to reduce residual and uneven settlement, decrease earth pressure, prevent lateral displacement and improve earthquake resistance of port and airport facilities in which dredged slurry is mixed with stabilizing agent and either air foam or expanded polystirol (EPS) beads of 1 to 3 mm in diameter (Tsuchida, 1995; CDIT, 2004). Density of the stabilized soil can be obtained from 0.6 and 1.5 g/cm^3 by controlling amount of air foam or polystirol beads, and water content of soil. As clayey soil to be mixed has a relatively high water content, the treated soil has high liquidity at mixing stage and then looses liquidity quickly. Execution procedure of the method is very similar to Premixing Method, which includes dredging, transporting, mixing, placing and curing steps.

The earth pressure of the stabilized soil is very small by the effect of its relatively large strength as well as light-weight, which can downsize superstructure such as caisson and sheet wall. The method has been applied to landfill or backfill behind a newly constructed quay wall, reinforcement of existing structure, embanking of adjacent work, and submerged backfill and embanking on soft ground.

4.2 Application to earthquake disaster mitigation

Figure 7 shows an application of the method at Kobe port where a concrete type quay wall was damaged by the Hyogoken-Nambu earthquake (Wako et al., 1998). The concrete caisson displaced horizontally and titled in the earthquake. As the amount of displacements were within the allowable values, the caisson was used without re-positioning but the backfill was partially excavated and replaced by stabilized soil in order to reduce the static and dynamic earth pressures acting on the caisson. The design unit weight and strength of the stabilized soil were 1.4 tf/m^3 and 100 kPa respectively.



(a) section view

(b) execution of improvement at site

Figure 7: Application of Lightweight Treated Soil Method at Kobe port

CONLUDING REMARKS

In this paper, the applications of three soil admixture stabilization techniques, Deep Mixing Method, Premixing Method and Lightweight Treated Soil Method, to earthquake disaster mitigation are briefly introduced. The improvement type and mechanism of the technique are different each other. However, the applications introduced in the manuscript clearly reveals that all the methods have the high applicability to earthquake disaster mitigation. These stabilization techniques have been applied successfully to various site and improvement purposes in the past and expected to develop further for more various sites and improvement purposes in the future.

REFERENCES

Coastal Development Institute of Technology., 2002. *The Deep Mixing Method -principle, design and construction-*, Balkema publishers, 123.

Coastal Development Institute of Technology., 2003. *The Premixing Method -principle, design and construction-*, Balkema publishers, 140.

Coastal Development Institute of Technology., 2004. *The Lightweight Treated Soil Method -new geomaterials for soft ground engineering in coastal areas-*, Balkema publishers, 120.

Namikawa, T., Koseki, J. and Suzuki, Y., 2007. Finite element analysis of lattice-shaped ground improvement by cement-mixing for liquefaction mitigation, *Soils and Foundations*, Vol.47, No.3, 559-576.

Noda, S. 1991. Waterfront development and liquefaction, *Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, 'Tsuchi-to-Kiso'*, Japanese Geotechnical Society, Vol.39, No.2, 1-4 (in Japanese).

Suzuki, Y., Saitoh, S., Onimaru, S., Kimura, G., Uchida, A. and Okumura, R., 1996. Grid-shaped stabilized ground improved by deep cement mixing method against liquefaction for a building foundation, *Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, 'Tsuchi-to-Kiso'*, Japanese Geotechnical Society, Vol.44, No.3, 46-48 (in Japanese).

Tsuchida, T., 1995 Super geo-material project in coastal zone -development of high quality geo-material by recycling bulky urban wastes-, *Proc. of the International Symposium on Coastal Ocean Space Utilization*, 391-401.

Wako, T., Tsuchida, T., Matsunaga, Y., Hamamoto, K., Kishida, T. and Fukasawa, T. Use of artificial light weight materials (Treated soil with air form) for port facilities, Journal of the Japan Society of Civil Engineers, No.602/6-40, 35-52 (in Japanese).

Zen, K., Yamazaki, H., and Sato, Y. 1990. Strength and deformation characteristics of cement treated sands used for premixing method, *Report of the Port and Harbour Research Institute*, Vol.29, No.2, 85-118 (in Japanese).

Analysis of traffic flow at bottleneck intersections in Dhaka and proposal of traffic control improvement plan

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ABSTRACT

There are various kinds of vehicles used in road traffic in developing countries. In such a condition of mixed traffic, it is not easy to estimate SFR (Saturation Flow Rate), which is an important factor in the signal control design. As a result, traffic signals are controlled inappropriately, which sometimes produces serious congestion at the intersection. Moreover, driving manners are not so good and it makes the situation more complicated.

This study aims to analyze traffic flow at intersections in order to identify the cause of traffic congestion under mixed traffic situation. Video observation was conducted at a bottleneck intersection in Dhaka City, Bangladesh, and the traffic flow was analyzed to estimate the SFR and the capacity of the intersection. Based on the result, some improvement plans were proposed and discussed to increase the capacity of the intersection.

According to the result, improvement plans of signal phasing redesign and road geometric design modification had significant effects on the capacity improvement. And also, assuming disciplined behaviors of drivers, such as following lane marking and no stopping inside intersection etc, the situation became improved a lot. Therefore, it was implied that appropriate traffic control strategies and people's disciplined behaviors are both important to improve the situation of mixed traffic.

Keywords: *mixed traffic, signal control*

1. INTRODUCTION

1.1 Background

Traffic congestion is one of the most common and serious problems among Asian mega cities. It generates a lot of economical and social loss, and sometimes raises risks of traffic accident, which causes another loss. Therefore, it is very important to alleviate traffic congestion in order to realize a reliable and sustainable urban environment. For this purpose, traffic phenomena in the actual field should be appropriately understood first.

In the developing countries, road is used not only by normal passenger cars, trucks and motorbikes but also by various kinds of vehicles such as jeepneys, tuk-tuks, (auto-)rickshaws, tricycles, handcarts and so on. Traffic flow in such mixed traffic conditions is quite different from the ones in developed countries, so we need to know the characteristics of the mixed traffic flow to make appropriate countermeasures to alleviate traffic congestion.

Dhaka has a very large and dense population which is growing rapidly. However, there are no mass transit systems like subway or suburban railway which are essential transportation modes in large cities. As a result, a lot of traffic congestion happens (Figure 1) and it leads to serious environmental problems such as air pollution and traffic noise etc. Its traffic is characterized by mixed flow of traffic modes, especially auto-rickshaws and (manpowered) rickshaws as shown in Figure 2. It is very urgent issue to alleviate the congestion to support its urban activities.

Figure 1: Traffic congestion in Dhaka

Figure 2: Auto-rickshaws and (manpowered) rickshaws

1.2 Purpose

The purpose of this study is to clarify the characteristics of the mixed traffic flow, especially saturation flow rate (SFR) which is an important factor to deal with traffic at an intersection. A field survey at bottleneck intersections in Dhaka is conducted to obtain necessary data for this purpose. And based on the results, a couple of possible strategies to alleviate the traffic congestion are proposed.

2. STUDY SITES

Figure 3 shows a map of Dhaka. The old town and the city center are located in the southern part of the city and new residential areas which hold relatively rich people and their private vehicles are developed in the north. Therefore, the major direction of traffic is from the north to the south in the morning peak hours. Airport Avenue and Kazi Nazrul Islam Avenue are major streets to connect these areas and suffer from serious traffic congestion during the daytime. We selected two intersections along these streets according to the opinion from transportation experts in Dhaka, that is, Sonargaon intersection and Shahbag intersection.

Figure 3: Location of the study sites

2.1 Sonargaon intersection

Sonargaon is one of the busiest intersections in Dhaka located at the entering point to the city center from the north. It has 5 approaches and a big circular island in the center. The right-turn traffic is circulated around this circle like one at a roundabout. Because of this complex structure, different movements of traffic merge and diverge, which causes serious traffic congestion.

2.2 Shahbag intersection

Shahbag is an intersection located at the north end of the old town. It has 4 approaches and all left-turn traffic is separated by the dedicated channels. A lot of buses run and stop around this intersection to let passengers get on and off. Rickshaws are allowed to run only in the southern area form this intersection.

Figure 4: Video images at Sonargaon (left) and Shahbag (right) intersection

3. DATA COLLECTION

A field survey was conducted to collect necessary traffic data for the traffic flow analysis as follows.

3.1 Video observation

The two intersections were observed using video cameras. Video shooting points were set to cover all approaches of the intersections from the buildings around the intersections as shown in Figure 4. Video images were recorded from 7:30 am to 9:00 am to observe the morning peak hours.

3.2 Probe vehicle survey

Probe survey was conducted in conjunction with the video observation. 6 vehicles carrying handy GPS logger were prepared as probes. Figure 5 shows the driving routes of these probe vehicles. They were set to traverse the target intersections to gather information of the approaching roads.

Figure 5: Routes of probe vehicle survey

4. TRAFFIC FLOW ANALYSIS

4.1 Traffic volume and signal settings

Traffic volume and vehicle types were counted for all approaches from the observed video images. Signal control settings such as the total cycle time and the green time of each phase were also measured. The results are shown in Figure 4 and 5.

The major traffic flow enters Sonargaon intersection from approach I and III, that is, Kazi Nazrul Islam Avenue. Approx. 60% of the vehicles are cars and trucks, and there are relatively many auto-rickshaws, too. The cycle time of Sonargaon intersection is extremely long (413 sec). It often generates a long waiting queue of the right-turn vehicles which blocks the through traffic then traffic officers sometimes interrupt the traffic flow to let the waiting right-turn vehicles pass, which may give a further delay.

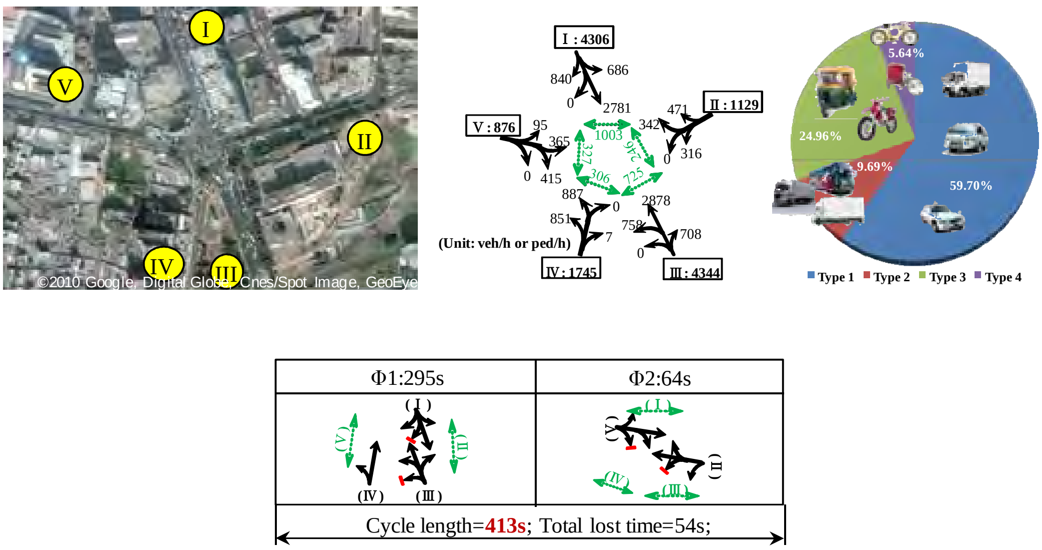


Figure 6: Traffic demand and signal settings at Sonargaon intersection

At the Shahbag intersection, the major direction of traffic is east-west. The ratio of cars and trucks is almost same as Sonargaon, but the ratio of buses are higher than that of auto-rickshaws in Shahbag. The cycle length (194 sec) is shorter than that of Sonargaon but it is still long compared with ones in developed countries.

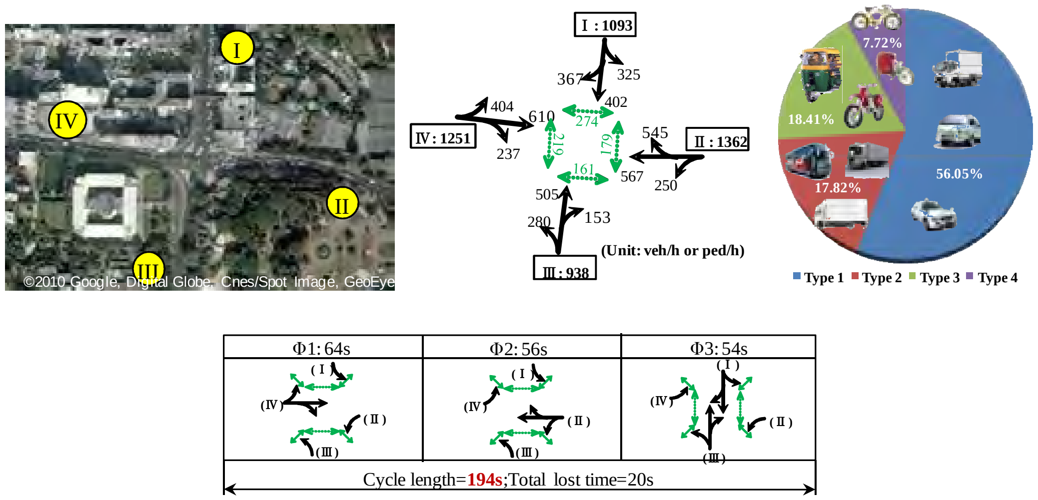


Figure 7: Traffic demand and signal settings at Shahbag intersection

4.2 Saturation flow rate (SFR)

Saturation flow rate (SFR) is a value of traffic flow per unit time which passes the stop line when there is enough traffic demand approaching from the upstream. Usually SFR is obtained as lane-based value, but the traffic in Dhaka rarely follows the lane discipline, therefore this study calculated SFR as approach-based value. Furthermore, a lot of drivers behave in undisciplined manner in Dhaka, for example, not following designated directional lanes, stopping inside the intersection, ignoring traffic signals etc. These behaviors of course deteriorate the efficiency of the intersection, which means, a significant drop of SFR.

Figure 8 shows the SFR value of each approach. Left bar of the graph is the current SFR value obtained from the video observation, and right one is the estimated value assuming disciplined driving behaviors by all drivers around the intersection. From this result, SFR could be increased by 10 – 20 % if the driving manner of the road users is improved.

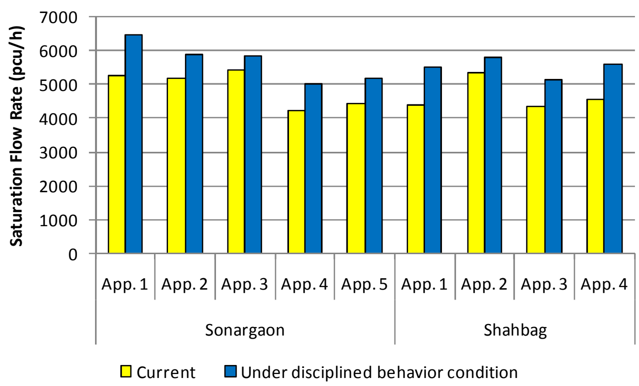


Figure 8: Saturation flow rate of each approach

4.3 Travel time

Travel time and travel speed was obtained from the location data recorded by GPS logger on the probe vehicles. Table 1 shows the results in each route in the time period of 7 am and 8 am. The value of average speed dropped from 7 am to 8 am, which means the congestion became worse as time proceeded. Figure 9 shows the trajectory of the probe vehicle running on the route 1 in a time-space diagram. Gentle or flat parts of the slope mean that the speed of the vehicle was slow. We can understand it took more travel time in the period of 8 am and there were a couple of long waiting periods in front of major intersections.

Table 1: Travel time and speed of probe vehicles (from suburbs to center)

	7 am			8 am		
route	travel distance (km)	travel time (s)	average speed (km/h)	travel distance (km)	travel time (s)	average speed (km/h)
1	6.575	887	26.7	6.900	2043	12.2
2	9.490	1694	20.2	5.500	2868	6.9
3	9.123	1169	28.1	8.617	1358	22.8
4	9.874	1631	21.8	9.901	2624	13.6
5	11.356	1312	31.2	11.221	3672	11.0
6	6.300	849	26.7	5.503	1700	11.7
		average:	25.2		average:	12.0

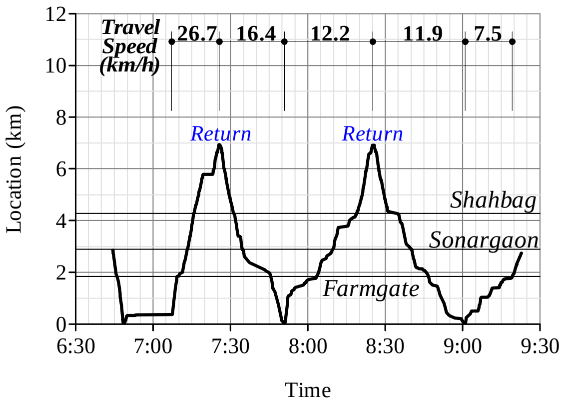


Figure 9: Time-space diagram of probe vehicle in route 1

5. PROPOSAL OF IMPROVEMENT STRATEGIES

Through the field observation and analysis mentioned above, the causes of traffic congestion in Dhaka can be explained as follows.

Firstly, undisciplined behaving manners of many drivers are pointed out. It makes the situation very complex and amplifies the congestion. It also generates safety risk, which may leads to traffic accidents. Secondly, the signal control scheme is not appropriate. The cycle time is too long (especially at Sonargaon), which causes gradual drop of SFR and leads to inefficient use of green time. Besides, manual control by traffic officers based on their experience and feeling sometimes makes the situation worse. And thirdly, geometric design of the intersection is not appropriate. For example, the size of Sonargaon intersection is very large, which requires long clearance time and makes big loss. On the contrary, Shahbag intersection has relatively narrow upstream approaches even though the width at the stop line is wide, then it cannot utilize the full capacity of the intersection.

Based on this consideration, strategies to improve the current traffic congestion are proposed as follows.

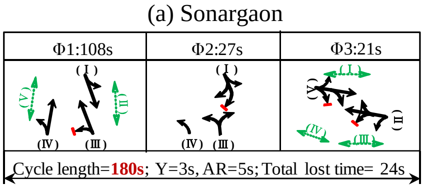
5.1 Dissemination of disciplined driving behavior

As undisciplined behaviors cause not only traffic congestion but also traffic accidents, it is important to disseminate disciplined driving manners among drivers. This improvement makes benefit not only at the target intersections but also in other area of the city. Some kinds of educational program should be offered to have people comply the traffic rules.

5.2 Redesign of signal phasing

The signal phasing plan can be modified in order to increase the capacity of the intersections. Based on the traffic demand and SFR obtained from the field observation, the optimum cycle time and split (ratio of green time) are calculated as shown in Figure 10. Here, the cycle time is shortened significantly and the phasing pattern is changed to reduce the drop of SFR and the loss time.

(a) Sonargaon



(b) Shahbag

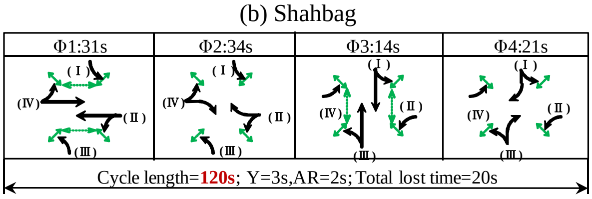


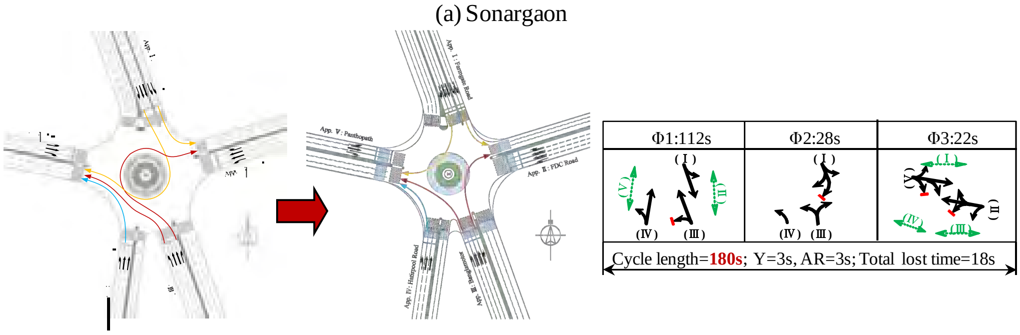
Figure 10: Proposed signal phasing plan

5.3 Modification of geometric design

Figure 11 shows the modification plan of the geometric design as well as the updated signal phasing plan of the target intersections. At Sonargaon intersection, the central island is downsized so that the right-turn vehicles can move near side each other, which can reduce the conflicts and the through traffic blockage. The stop line is also shifted forward so as to reduce the clearance loss time. Signal control parameters like cycle time and split are recalculated due to these changes, too.

At Shahbag intersection, the width of the approach II and IV (East-West) is widened for a certain length. It allows more traffic to enter the intersection simultaneously and keeps the SFR high during the green time. As a result, the green time for this direction can be saved and this can be converted to the green for the other movements.

(a) Sonargaon



(b) Shahbag

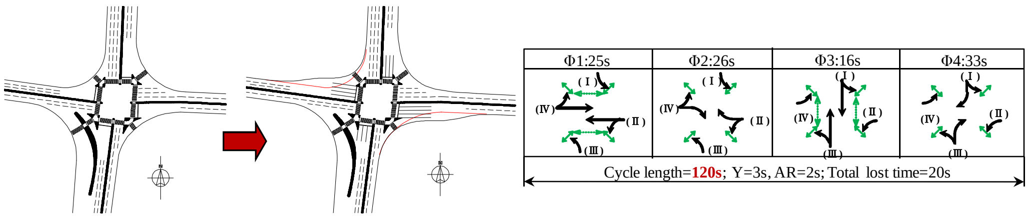


Figure 11: Proposed modification of geometric design

Finally, the amount of the capacity improvement by these proposed strategies are shown in Figure 12. Case 1 to 3 corresponds to the strategies described in Section 5.1 to 5.3. The intersection capacity increases significantly, by approx. 50% at Sonargaon and approx. 100% at Shahbag. These values are large enough to alleviate traffic congestion generally, so we believe that an appropriate infrastructure design, traffic control and education have a large potential to improve the traffic condition in Dhaka drastically.

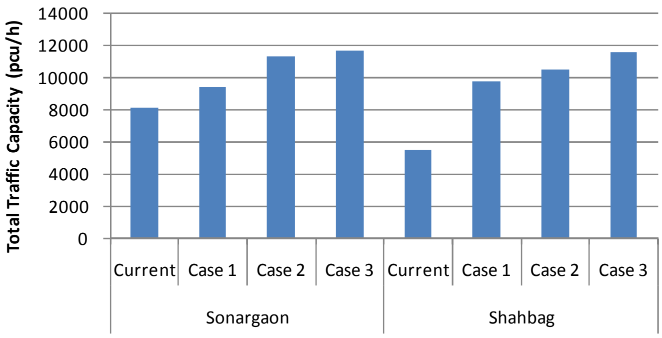


Figure 12: Improvement of the intersection capacity

6. CONCLUSIONS

This study focused on the analysis of the traffic flow in Dhaka, which holds a variety of vehicle types on the road. The characteristics of the mixed traffic were understood and the causes of the traffic congestion were identified through the field survey and the analysis. Then a couple of improvement strategies which cover infrastructure design, traffic control and human behavior were proposed, and they were evaluated to have a good potential to improve the traffic condition.

This study revealed only a few aspects of the traffic situation in a developing country, which is sometimes quite different from the one in developed countries, so we cannot apply conventional theories as it is. Further studies are needed to clarify the characteristics in such societies and to explore the possibility to apply our experience.

*Turkish experience on river flood risk management**

* The research study, this paper is based on, was conducted for the PhD Thesis in City and Regional Planning Department which was submitted to the Middle East Technical University in Ankara, TURKEY (2009).

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ABSTRACT

Turkey's current flood protection structure seems to be based on the surveys and assessments of a central authority and on its limited powers of intervention. The local municipal administrations are under different interests and pressures for development and land-use. It seems essential to integrate flood risk mitigation efforts with the local planning system and to involve municipalities in their estimations of risks and its declaration on official duty, as contemporary international approaches indicate. This conviction is based on a sample survey of four cases of riverine cities; namely Bartin, Batman, Aydin, Hatay in Turkey, and on a review of current approaches in a sample of international cases.
Findings on case cities indicate that river floods turn into destructive disasters mainly due to tolerant land-use decisions. Inaccurate and discrete implementations and developments in and through the river basins are second source of flood losses. Currently, neither urban development plans nor available flood plans are equipped with necessary measures to mitigate risks.
Findings also indicate that current vulnerabilities are greater in value than investments made to curb flood risks. Independent and discrete efforts of mitigation seem to generate illusory feelings of safety, which aggravates vulnerabilities.

Keywords: flood risk management, urban planning in Turkish riverine cities

1. INTRODUCTION

This paper mainly considers flood disasters which have been continually effective and which will most likely increase in intensity and frequency in urban areas of Turkey due to global warming and climate change. The research, the paper is based on, is conducted on four riverine cities; namely Bartin, Batman, Aydin, Hatay, each of which has different climatic and geomorphologic conditions. Since the main purpose of the research is to reveal the causes of continual losses other than hydro-meteorological factors, urban development processes are mostly investigated in a historical perspective for each case. Instead of basically focusing on case-specific planning decisions and development processes, the common approaches of central and local governments towards flood events are identified and conceptualized to describe the relation between flood protection, so-called 'management' strategy and the urban planning processes in Turkey. In this respect, moreover, current international agenda, related literature and implementation strategies of various countries about flood 'risk management' issue are crucial to be mentioned. For this reason, the main aspects of flood risk management and its prevailing strategies that are shared by most of the other flood prone countries are examined in order to make a comparison with Turkey case.

The main claim of this paper, as a result, current urban planning system that has formed Turkish cities of today has not conformed to 'flood risk management' approach. In other words, the cities that have been developed by such prevailing planning system and control mechanisms are prone to high flood risks due to ineffective planning tools and settings that could not comprehend the inner mechanisms of 'risk concept'. The final interpretations on the research results and contributory interventions for the improvement of current planning system are mostly based on a kind of quantitative research on recent vulnerability states of case areas according to available hazard maps.

2. CONTEMPORARY APPROACHES ON FLOOD RISK MANAGEMENT

Through centuries the most common way of dealing with flood disasters has been protective walls, levees, dunes whose heights were defined depending on the highest water level observed in previous event. However, each following event has proven that only depending on such structural works have not been sufficient enough; contrarily they have caused even more devastative losses. In addition, behind the levees 'so-called absolute safe areas' have attracted investments together with dense populations. For instance; 1993 Mississippi flood disaster due to the failure of protective levees was the milestone for flood risk management in U.S. (Cigler, 1996). Similar to that in the Netherlands due to 1993 and 1995 disastrous floods it was admitted that a reform was required which can be done by integrating risk management strategies into flood issues (Jorissen, 1998). Hence, today's prevailing approach shared by many countries claims 'living with floods' opposed to the conventional one that tries keeping floods away from the human life.

Last two decades on the international arena the great impacts of many great disasters have pointed out that today's communities, regions and nations can no longer afford simply respond to and recover from natural disasters. Hydro-meteorological disasters including floods have taken larger amount among the other disaster types (EM-DAT, 2005). It is also evident that the number of flood disasters, from 20 to 160 events per year has increased since 1975 (Pilon, 2003). The adverse effects of global warming as well as the increase in populations settled on vulnerable areas are considered as principle reasons. It is also claimed that the magnitude and frequency of flood events tend to be aggravated in the near future due to global warming and climate change according to some scenarios and projections (Lehner et al., 2006).
Hence, above mentioned first hand experiences of many countries and common concerns on the international arena like United Nations (Albrito, 2008) have

admitted the main idea which requires not only 'disaster response' but also 'disaster risk reduction and mitigation' while dealing with natural disaster risks.

2.1 Flood risk management: definition and main aspects

Risk concept, originally designed in the area of modern business administration, contributes to the management of flood disasters like any other natural disasters. It is simply defined as a probability that a hazard will turn into a disaster. As a function of hazard and vulnerability it can be managed by a sequence of actions; such as identifying possible damages, estimating how much risk concentrated in which places and taking measures to reduce risks before the real event occurs (ISDR terminology; Kaplan and Garrick, 1981; Mileti, 1999; Balamir, 2001). In order to achieve risk mitigation in an effective and economic way the priorities should be defined in three sub-areas; namely risk avoidance, reduction and sharing (Balamir, 2000).

According to the results of descriptive research on flood risk management literature common approach, which is still developing and becomes wide-spread in many countries is to integrate structural (engineering) and non-structural measures (urban policy and planning) into whole watershed area. It is admitted that this approach requires first of all dynamic and holistic modeling, detailed recording, and regular monitoring for identifying and assessment of the risks. Secondly, it requires mitigation planning that defines basically spatial planning integrated with flood risk management. Reclamation of river beds, constructing levees, flood walls, dams are several structural measures that keep the flood waters away from the settlements, counted as risk reduction strategies. Based on the spatial information about flood hazards and up-to-date flood risk maps non-structural strategies such as land-use decisions and settlement lay-out planning can be used as the avoidance of risks by which settlements can be kept away from disaster prone areas. However, there are always residual risks that cannot be absolutely eliminated but instead can be reduced to a great extent. By the help of effective funding system including aids, donation and taxation strategies, as well as well-established insurance system together with reliable early warning system such residual risks can be reduced as much as possible. In short, flood risk management can be conceptualized as the process of sequential actions shown in figure 1.

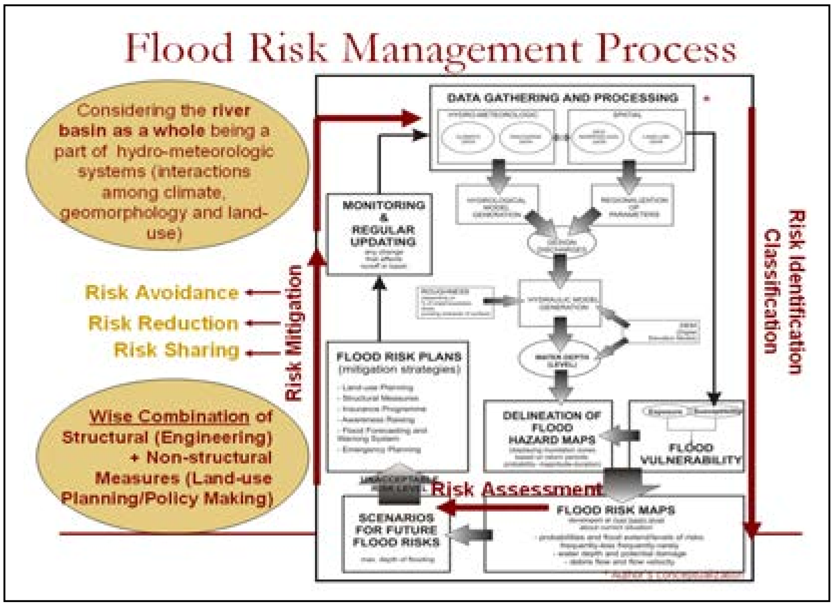

Figure 1: Conceptualization of flood risk management process (Senol Balaban, 2009)

2.2. Implementation strategies: research on country-specific examples

As explained above, flood risk management explores new methods to live with floods with reduced risks. Deep surveys on countries; namely Netherlands, France and Germany give us several examples about such methods and implementation strategies. For instance, in the Netherlands case water elements that may cause flooding sometimes can be used as complementary, multifunctional area in order to be considered as strategic instrument rather than just being a regulatory task (Woltjer and Al, 2007). In German case, limiting urban development and reducing damage potential are main policies while restraining flooding decentralized in order to give ‘more room for rivers’ (Friesecke, 2004; Wilke, 2004). A committee of stakeholders at ‘river basin district level’ can also work actively for concerted and coordinated action using several compulsory restrictions based on flood risk levels in France river basins (MEDD, 2006).

As a result, common key points that are observed in these countries can be summarized as follows. Administrative bodies from central to local levels are responsible for managing basin-wide risk maps, mitigation plan alternatives, land-use zoning and urban design solutions basically to raise retaining capacity and ease drainage. A certain risk level can be reduced at the source of a hazard, such as increasing the water retention capacity of the catchments, frequently inundated flood-plains as urban parks, nature areas or ecological reserves, while prohibiting the locating of investments and assets in these flood plains. On the other hand, less frequent and low risk areas can be used for residential purposes, however they ought to be constructed and located above the pre-determined flood level. In order to implement such policies certain planning tools are used and followed by well-established control mechanisms (Senol Balaban, 2010).

3. TURKEY'S FLOOD PROFILE AND RESEARCH RESULTS

Floods which are the most wide-spread hydro-meteorological hazards in Turkey turn into disasters in two-ways. Rivers can overflow from their inadequate beds when heavy rainfall occurs. Secondly, after sudden rainfall inner city inundations as flash floods can be observed due to inadequate drainage and infrastructure as well as closed river channels in urban areas. Since almost all provinces have been affected from flood event, it can be said that most of the riverine cities are prone to chronic flood disasters and have frequently lost lives and properties. For instance, last 60 years 1232 casualties and 23 million hectares of flooded land in 1930 separate events was observed according to official records of State Hydraulic Works (SHW, 2009). Annual economic loss is estimated approximately 100 million US dollars as declared by General Directorate of Disaster Affairs (GDDA) (Taymaz, 2008).

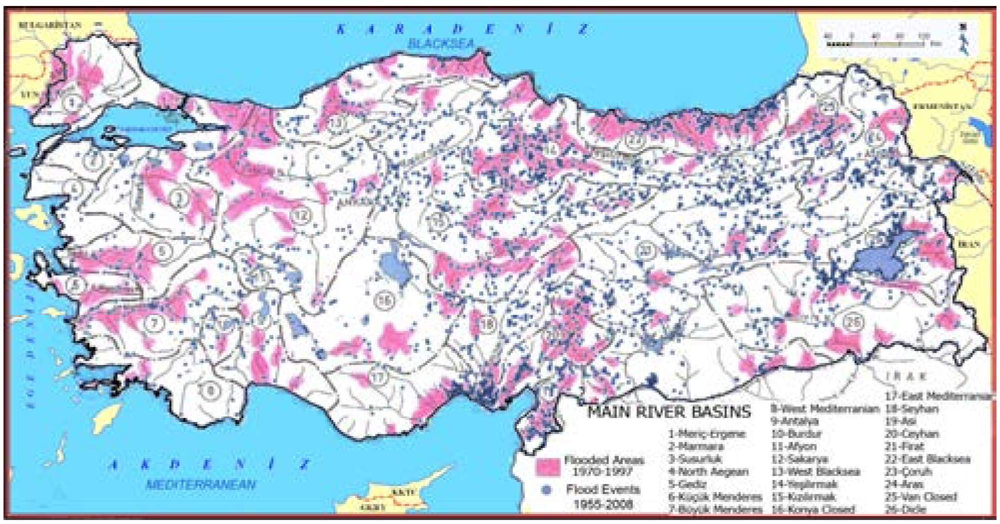

Figure 2: Spatial distribution of flood events and flooded areas (SHW, 1998; Gokce and others, 2008)

According to climate scenarios of the region Turkey belongs to, nationwide mean temperature is expected to increase 2-3 C° while total annual precipitation is expected to decrease in next 70 years (Demir and others, 2008). On the other hand, it is also expected to observe increase in regional and local extremes in precipitation. In fact, until 2009 actual weather statistics indicates that normal then warmer temperatures as a continuous anomaly have been observed since 1993 (Turkish State Meteorological Service-TSMS, 2010).

3.1 Purpose and scope of the study

Contrary to the recent improvements in flood risk management approach in the international agenda Turkey has still depended on conventional protection methods mainly. Despite such methods, however, it is observed that damages on life and property still continue particularly in urban areas. For example, recently

(September 2009) in Istanbul and Marmara region, 32 people were killed and 6766 housing units, 903 working places were damaged or collapsed due to flash floods. Economic losses from floods every year are also increasing because the dense urban areas, metropolitan centers that are located on highly valuable land are prone to flood hazards like the example above. Therefore, it is necessary to find out the main causes that have resulted in continual damages on life and property. For this reason this study aims to analyze not only the flood events chronology of selected urban areas but also city development history together with (un)planned decisions which affect the scale of the next flood disaster. For this purpose, it is crucial to select case areas that have continual flood history with very few similarities in geomorphologic and climatic settings in order to focus on common causes that are independent from physical settings (figure 3).

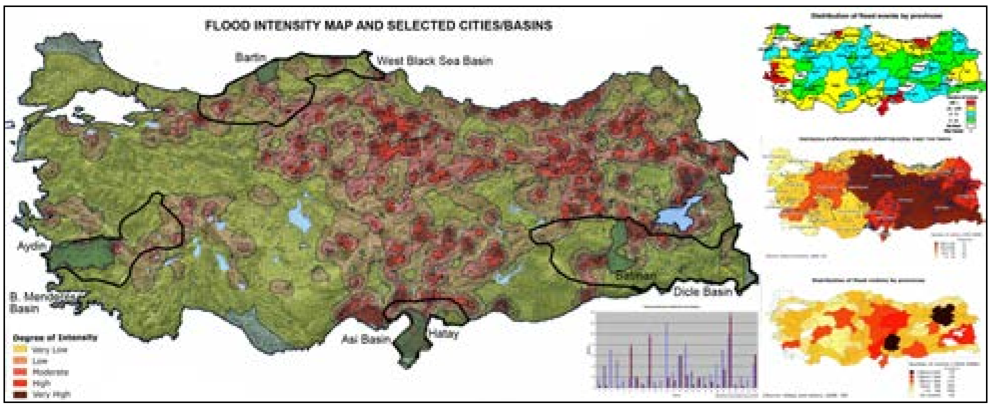

Figure 3: Selection criteria and selected 4 river basins and riverine cities (Gokce and others, 2008; Taymaz, 2008; SHW 1998 and 2009)

3.2 Research Methodology and Results

First of all, empirical research was carried out for each selected case areas shown in figure 3 under following topics:

- Physical settings of major river basin located
- Previous flood events, reports and recommendations
- Plan preparations and major decisions
- Impacts of settlement's growth regarding floods
- Existing territorial (regional) plan decisions
- Persisting vulnerabilities and values in cities

Although such topics providing city flood profile is extremely necessary for implementing flood management strategies, it is hardly possible to get all related records from one institution. Another difficulty is that there is also no standardization for the data recording and sharing. Therefore, one or another topic cannot be obtained in some cases. For example, flood vulnerability analysis were done for only two of them, 'Bartin' and 'Batman', since the other two have no available flood hazard map to be referred. Individual case study results will be summarized in the section 3.2.1.

As mentioned several times from the beginning, it is essential to find out main causes behind the continual flood losses in urban areas some of which are selected as case areas. It is also necessary to understand inconsistencies between urban planning and flood protection works. For this reason second part of research requires more deep analysis on existing institutional structure to conceptualize what could be done to improve the system. Results of such research can be found in the section 3.2.2.

3.2.1 Results of research on individual cases

Findings of the case-study research lead us to classify these causes in two broad categories, observed at basin level and at urban level. There is a lack of monitoring, control and coordination at the **basin level**. Local ad-hoc interventions may temporarily solve the flood problem at a specific location. However, this leads to the transfer of flood problem to another location. Any change in land-use or in the course of river generally has basin-wide impacts depending on the hydrological cycle.

At the **urban level,** many examples of implementations and developments that have caused greater losses of river floods and inundations are observed in all cases. Tolerant land-use decisions and loose development controls have created substantial vulnerabilities in urban areas. These interventions are listed as follows:

- Capacities of infrastructure systems in urban areas are decreased, and become inefficient due to the decisions of density rise in built-up areas,
- Permeable surfaces (forests, parks, green areas, valleys, recreation areas) are engulfed by expanding hard surfaces (concrete spaces, pavements, buildings),
- Riverbeds, flood-prone lands and valley bottoms are not only occupied by unauthorized developments but also by some public facilities and services like streets, public buildings closing river tops. Also flow discharges of rivers are decreased by a number of inaccurate interventions (discharging direct sewage/rainwater system, damping solid-wastes and debris, and insufficient cleaning and maintenance services),
- Infrastructural deficiencies caused by inaccurate and discrete engineering interventions such as inaccurate design of transport bridges and concrete channel construction are also observed in most of the cases.

Due to the availability of official flood hazard maps the vulnerability analysis for 2 cases was conducted in order to determine, and to assess the probable volumes of losses together with their values within the flood-prone areas (figure 4). Besides, the likely losses are compared with the costs of measures applied to curb flood risks. In ‘Bartin’, it’s calculated that current (2009) vulnerabilities in value terms are 5 times larger than the structural investments made to mitigate flood risks. Value of current vulnerabilities in ‘Batman’ appears to be 3 times more than the value of previous structural investments.

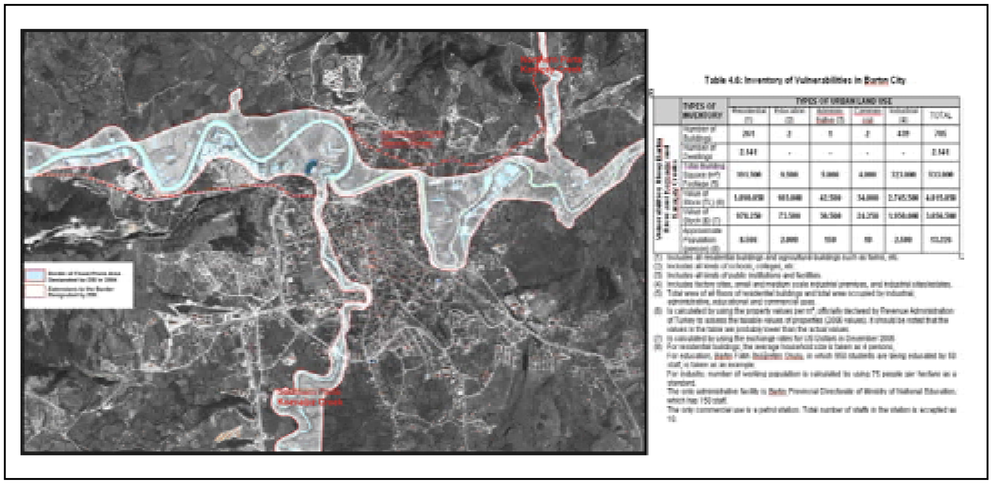

Figure 4: Inventory of Vulnerabilities of one of the case areas (Senol Balaban, 2009)

3.2.2 Results of research on institutional structure

Findings on institutional system and planning legislation indicate that Turkey's current flood protection structure seems to be based on the surveys and assessments of a sole central authority, State Hydraulic Works, and on its limited powers of intervention. Since there is no administrative power and mechanism to monitor and control major river basins, both development decisions and partial flood protection measures in any part of basin may also cause flood losses in other parts. The local municipal administrations, on the other hand, are under different interests and pressures for development and land-use. Besides neither urban development plans nor available flood hazard maps are equipped with necessary measures to mitigate risks.

4. CONCLUSION

Recent disastrous events have shown that flood disasters are going to be more frequent and widely destructive on our cities due to the adverse impacts of global warming. The size of the consequences of such impacts could be beyond the social and financial capacities of many countries. Therefore, it is necessary to be prepared for the worse case scenarios and the most probable situations beforehand. Such approach seems to be provided by the concept of risk and risk management system whose wider scope includes all risks to be clearly identified, classified, assessed, analyzed and effectively mitigated. Hence, in the case of Turkey there is an urgent need for preparation and active use of flood hazard, vulnerability and risk mapping. Such maps should be provided for main river basins across the country. Then each local authority should take into consideration before the urban development planning and implementation processes. Such maps are powerful tools for directing mitigation policies either at regional or local level both in new developing and already developed areas. However, policy implications in developed areas could be the challenging process which requires further research and analysis.

Moreover, from the wider perspective it is quite necessary to restructure the current administrative and legal framework in order to establish an integrated flood risk management system for Turkey. To establish for each major river basin 'The Commission of Integrated River Basin Management' which may be based on the Law of Local Government Union can be one alternative structure. This commission will be responsible for preparation of 'Flood Mitigation Plan' that is based on flood hazard and risk maps supported by the consent of related institutions. It is also necessary to include public people, NGO's and Professionals during such decision-making process. Such kind of planning scale corresponds to currently used Territorial Plan scale that takes into account basin-wide establishments, settlements, strategic spots and decisions. Development plans for each settlement in a basin be prepared in accordance with Territorial Plan Decisions. Such kind of administrative systems is described in figure 5.

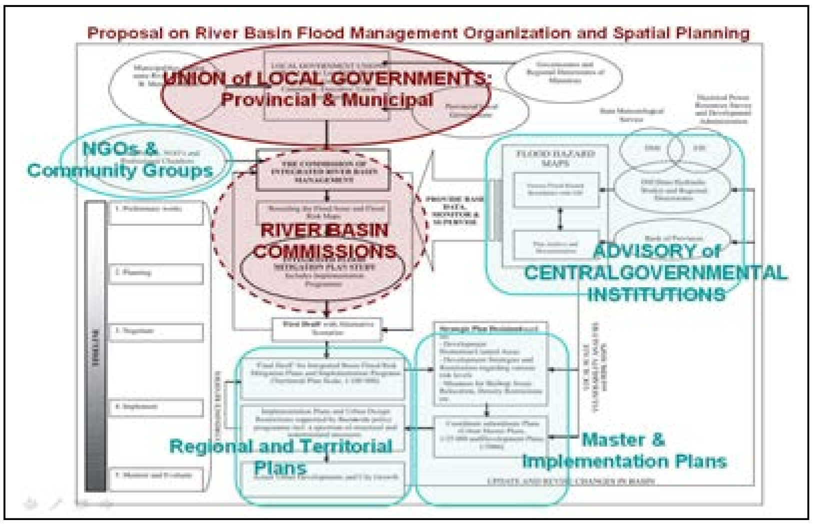

Figure 5: Proposal on river basin flood management and spatial planning (Senol Balaban, 2009)

On the other hand, it is also crucial to provide more effective mitigation control at local level. Therefore, the compulsory declaration of flood vulnerabilities by municipalities themselves in their entitlement for special subsidies could raise the general level of awareness, could curb further vulnerabilities, and contribute to the articulation of planning methods. Besides, such vulnerability analysis is appropriate for the rational decision-making and strategy development avoiding urban developments on flood-prone areas because once development is not controlled or permitted on such areas the volume of potential losses goes beyond the structural investments, which only bring some partial and temporary solutions rather than effective mitigation. As a result, it appears essential to integrate flood risk mitigation efforts with the local planning system and to involve municipalities in their estimations of risks and its declaration on official duty, as contemporary international approaches indicate.

REFERENCES

Albrito, P., 2008. "Building a Local Governmental Alliance for Disaster Risk Reduction", in the International Workshop, *For a New Governance of Natural Risks,* in 27-28 October 2008, Istanbul.

Balamir, M., 2000a. "Is a New Earthquake Strategy Developing in Turkey? Law and Institutional Changes and Recent Priorities after 17 August 1999", in *Journal of Architecture*, (295) (*In Turkish*) .

Balamir, M., 2000b. "Reproducing the Fatalistic Society: An Evaluation of the Disasters and Development Laws and Regulations in Turkey, *in Urban Settlements and Natural Disasters*, edited by Emine Komut, UIA-Chambers of Architects Publication.

Cigler, B. A., 1996. Coping with Floods: Lessons from the 1990s, in *Disaster Management in the U.S. and Canada,* pp. 191-213, Richard T. Sylves and W. L. Waugh, Jr. eds, Charles C. Thomas Publisher LTD, U.S.

Demir İ., Kılıç G. and Coşkun M., 2008. 'Climatic Projections for Turkey by PRECIS Regional Climate Model: HaDAMP3 SRES A2 Scnario, IV. Atmospheric Sciences Symposium, 25-28 March 2008, Proceedings, s. 365-373, ITU, Istanbul (*In Turkish*)

EM-DAT, 2005. http://www.unisdr.org/disaster-statistics/occurrence-trends-century.htm.

Friesecke, F., 2004. "Precautionary and Sustainable Flood Protection in Germany – Strategies and Instruments of Spatial Planning", pp. 1-17, in *3rd FIG Regional Conference*, 3-7th October 2004, Jakarta, Indonesia.

Gokce O. and others, 2008. *Disasters Inventory: Spatial and Statistical Distribution of Disasters*, General Directorate of Disaster Affairs, Ankara (*In Turkish*).

Jorissen, R. E., 1998. Safety, Risk and Flood Protection Policy, in *RIBAMOD,* pp. 57- 72, edited by R. Casale.

Lehner B., Döll P., Alcamo J., Henrichs T., Kaspar F., 2006. 'Estimating The Impact of Global Change on Flood and Drought Risks in Europe: A Continental, Integrated Analysis', *Climate Change*, Vol 75, p 273-299, Springer.

MEDD, 2006. Presentation of Water Department of Ministry of Ecology and Sustainable Development.

Pilon, P. J. ed., 2003. "Guidelines for Reducing Flood Losses", United Nations.

Senol Balaban, M., 2009. *Risk Society and Planning: The Case of Flood Disaster Management in Turkish Cities* Unpublished PhD Thesis, Middle East Technical University (METU), Ankara.

Senol Balaban, M., 2010. 'Reducing flood vulnerabilities in urban areas of Turkey by means of integrated basin management' in the Proceedings of *15th Inter-University Seminar on Asian Mega-Cities' in the International Symposium on City and Waterfront*, 11-13th March 2010, The University of Tokyo, Tokyo

SHW, 1998. *Flood Annuals*, Volumes 5, 6, 8, Ankara (*In Turkish*)

SHW, 2009. Statistics based on Annual Flood Records done by Investigation and Planning Division of General Directorate of State Hydraulic Works.

Taymaz, M., 2008. Power-point Presentation in 10th Roundtable Meeting (11 January 2008) held by Middle East Technical University - Disaster Management and Research Center, Ankara (*In Turkish*).

TSMS (Turkish State Meteorological Service) Official Web-site, 2010. *Evaluation Report of Climate Data of the year 2009*, Ankara (*In Turkish*).

Wilke, K., 2004. WMO/GWP "Integrated Flood Management Case Study – Germany: Flood Management in the Rhine and Elbe River Basins" in Associated Programme on Flood Management, Technical Support Unit eds.

Woltjer, J. and Al, N., 2007. "Integrating Water Management and Spatial Planning: Strategies Based on the Dutch Experience", pp. 211-221, in *Journal of the American Planning Association,* Vol. 73, No.2.

Disaster Risk Reduction of Highly Vulnerable Urban Areas through Urban Re-Development Case Study of Barangay Rizal, Makati, Philippines

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ABSTRACT
The United Nations General Secretary Global Assessment Report on Disaster Risk Reduction (GAR/DRR) (UNISDR 2009) lists urban risk as one of the key threat to the safety of humanity. It particularly emphasizes the challenge of reducing the impact of disasters on the poor. Yet, the vulnerability of the urban poor is escalating due to pressure from urbanization, the competition for scarce resources, and weaknesses in governance structures. In most cases, vulnerability reduction action resolves to displacing communities from high risk areas. However, these approaches are not always viable.

What then are the solutions for reducing the vulnerability of highly-vulnerable poor communities short of the undesirable option of displacing its population elsewhere? This project attempts to find an approach through Risk-Sensitive Urban Redevelopment. This approach combines in a single solution the reduction of risk and the improvements of emergency management capacity, with the improvement of the socio-economic and the living conditions of the residents.

Risk-sensitive urban redevelopment requires a different planning approach that is little known and largely untested elsewhere by planners. The Risk Sensitive Urban Redevelopment Plan of Barangay Rizal demonstrates how a long-term plan can be developed to guide future development within the ultimate goal of reducing exposure to hazards. The plan was developed using a participatory approach by an integrated team consisting of technical experts, barangay leaders, representatives of the community, and Makati city officials.

Keywords: disaster risk reduction, risk sensitive urban redevelopment planning, mainstreaming, participatory process, urban poverty reduction

1. THE CASE OF THE POOR AND HIGHLY VULNERABLE URBAN AREAS

The vulnerability of the poor and less privileged is indicated as a significant challenge to improving socio-economic equity and reducing human and economic losses from disasters. Disasters add to poverty by further depriving the poor and affecting those who are at the margin of poverty. Relieving the vulnerability of the urban poor has been faces formidable challenges, including lack of public and private investment, unclear land and property ownership, profiting from the informal housing market, and political influence. In some cases, government has resorted to relocation to deal with areas of informal settlers that are highly vulnerable (e.g., unstable hills, water ways, etc.). However, in many cases relocation is not a viable and in-situ re-development solution must be found.

2. RISK SENSITIVE URBAN REDEVELOPMENT

For highly urban settings, re-development is often the preferred methods for development since most of the land is already developed. Urban re-development is of particular interest to disaster risk reduction since it represents an opportunity for reducing risk to older structures and facilities, which are often associated with the highest physical and socio-economic vulnerabilities. The re-development processes are typically driven by economic objectives and are most of the time rely on private investments. In exceptional cases (e.g., slum rehabilitation programs), re-development is used as a means to reduce informal housing. Just like in the case of land use planning, urban redevelopment projects most often are not risk sensitive, thus missing one of the very few opportunities to reduce urban risk. Traditional planning methodologies need to be reviewed and re-formulated to be risk sensitive.

Fig. 1 Process for Risk Sensitive Urban Redevelopment

3. GENERAL DESCRIPTION OF THE PLANNING AREA

The Barangay[1] Rizal Risk-Sensitive Urban Redevelopment Planning Project was undertaken by the Earthquakes and Megacities Initiative (EMI) in partnership with the Makati City Government, the community representatives of Barangay Rizal, and the Philippines Institute of Volcanology and Seismology (PHIVOLCS). It involves the urban redevelopment planning of selected zones in the Barangay to modify and lessen the physical, social, and economic vulnerability of the

[1] Barangay is the smallest geo-political unit in the Philippines.

community to earthquake-related hazards, while at the same time improving the livelihood and living conditions of the residents.

Fig. 2: Bird's-eye view of Barangay Rizal

Barangay Rizal (**Figure 2**) is one of the 33 barangays of Makati City. The barangay was chosen as pilot area for the project because of the negative combination of its susceptibility to earthquake hazards and its socio-economic conditions. Makati is one of the 17 cities and municipalities that comprise Metro Manila (See insert of Figure 3). It is considered as the country's financial and business center, being home to the headquarters of 40 percent of the top 1,000 multinational and local corporations. It has a total resident population of 510,383 (2007 Census) but this balloons to almost 3.7 million during weekdays because of people who come here to work, do business, or shop.

4. HAZARDS, VUNERABILITIES AND RISKS

Barangay Rizal in Makati City Philippines sits on an active fault, which makes it highly vulnerable to earthquake hazards such as surface rupture, ground shaking, land subsidence, liquefaction and fire following earthquake. The West Valley Fault runs along the northwestern portion of the barangay (**see Figure 3**).

Fig. 3 Map of the Planning Area showing the trace of the West Valley Fault

According to the Metro Manila Earthquake Impact Reduction Study (MMEIRS 2004), rupture of the fault can cause a magnitude 7.2 earthquake, which has the potential to cause severe damage to approximately 40% of the total number of residential buildings within Metro Manila, with an estimated 34,000 deaths and 114,000 injuries. Certain portions of the barangay are expected to suffer serious damage due to ground rupture. A rapid visual screening of buildings for seismic vulnerability revealed that at least 1 out of every 3 of the inspected structures may not withstand a seismic event of magnitude 7.2 or higher.[2] Buildings along the fault trace are particularly vulnerable. Factors that contribute to vulnerability of structures include old age, weak structural systems, irregularities in building form, and poor construction with substandard materials.

Its physical make-up of congested streets and lack of open spaces make emergency access and evacuation very difficult. The presence of unsafe buildings and structures and narrow and obstructed roads are the main contributors to the physical risk of the area. There are very few open spaces which can serve as space for evacuation, temporary shelter, and storage for debris in case of an earthquake or other disaster. Debris could block the roadways, fire could spread, and there could be thousands of people displaced from their homes for months. Barangay Rizal is also subject to frequent flooding and other hazards such as fires.

The physical risk of the area is exacerbated by the area's socio-economic vulnerability. The population is generally low-income with a high level of unemployed. Results of socio-economic surveys conducted in the area reveal that 16 percent of households have a combined monthly income that falls below the poverty line. More than half (54 percent) of the community's productive population are unemployed. About 45 percent are employed, but only 28 percent have permanent employment, while the rest either have contractual work or are self employed.[3] The inadequate economic capacity and the presence of highly vulnerable households contribute to the socio-economic vulnerability of the area. Moreover, there is inadequate capacity in terms of emergency preparedness and response.

5. RISK SENSITIVE URBAN REDEVELOPMENT FRAMEWORK (RSURF)

The risk-sensitive urban redevelopment framework (RSURF) in **Figure 4** shows sustainability, livability and disaster risk/ vulnerability (planning parameters) as the core considerations for the redevelopment planning of the pilot site. Further, the community and stakeholders' participation and political support which was applied cross-sectorally to identify and validate site development planning considerations; to assess and validate disaster risk and vulnerability; to identify issues/problems, goals, objectives; to develop and identify strategies and

[2] Fernando Germar, Tabassam Raza, and Fouad Bendimerad, "Report on Rapid Visual Screening of Buildings for Seismic Vulnerability," Working Paper, Makati Risk-Sensitive Redevelopment Planning Project, Earthquakes and Megacities Initiative, Philippines, June 3, 2009.

[3] Marino Deocariza, Marqueza Reyes, Nadia Pulmano, "Vulnerability And Capacity Analysis (VCA): An Assessment of the Social and Economic Vulnerabilities in the Redevelopment Planning Site," Working Paper, Makati Risk-Sensitive Redevelopment Planning Project, Earthquakes and Megacities Initiative, Philippines, December 10, 2009.

programs, projects and activities (PPAs); to develop, validate and advocate alternative scenarios/RSURP; and to refine and select the most appropriate RSUPR and Ordinance containing institutional framework.

This is the first project of its kind in the Philippines to address the redevelopment of a built-up urban area, keeping in mind the reduction of risk. Thus there are no local precedents which can serve as guide. In addition to the physical risks, the redevelopment plan took into account the following considerations related to implementation: 1) the stakeholders and their interests; 2) the nature of property ownership; 3) finance; and 4) political commitment. The stakeholders may not have the same intensity of interest, but their support and cooperation are essential to achieving success.

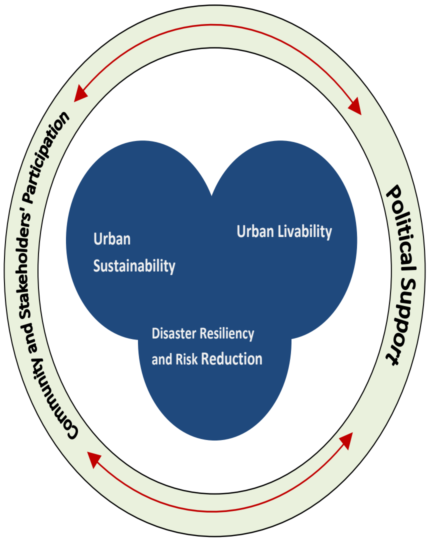

Fig. 4 Risk-Sensitive Urban Redevelopment Framework *(Source EMI, 2010)*

6. PARTICIPATORY APPROACH

The planning process used a highly participatory approach. A single integrated Project Implementation Team was put together that included technical specialists and officials from Barangay Rizal, Makati City and PHIVOLCS. Stakeholders were involved in all stages of the planning process.

A series of planning workshops was undertaken to engage the representatives of the community in the redevelopment process. First, they were oriented on the hazards and their vulnerabilities. Then they were asked to formulate their vision for the community, identify the major problems, and suggest solutions. Then, they participated in the identification of programs, projects and activities, and the validation and acceptance of findings and proposed redevelopment plan. This helped ensure that the plan reflected all stakeholders' interests, needs and aspirations. All findings and outputs from the projects were shared and validated with the community representatives. To create ownership in the redevelopment plan, the need for a continuous information and education campaign was emphasized. To further develop trust, members of the community were engaged in the data collection process. Training for disaster preparedness and skills training for livelihood improvement were also undertaken. The participatory planning process goes hand-in-hand with the planning process as indicated in **Figure 5**.

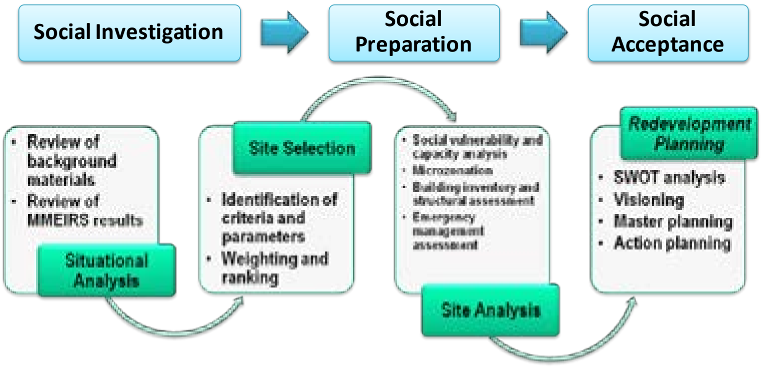

Fig. 5 Process for Participatory Risk-Sensitive Urban Redevelopment Planning *(Source EMI, 2010)*

7. RISK-SENSITIVE REDEVELOPMENT CONSTRAINTS

The project involved the preparation of a plan with the goal of transforming the high risk community into a safer, disaster-resilient neighborhood while simultaneously enhancing its urban fabric, economic vibrancy, social cohesion, public safety, and environmental quality. The challenge is to work with the stakeholders to develop options to reduce these risks and to have these options understood and accepted by the community.

The redevelopment plan for the site needs to consider how to reduce risk for these three major aspects: physical vulnerability, social and economic vulnerability; at the same time, it needs to improve the emergency management potential. For physical vulnerability, the main concern pertains to the structures built on top of the fault zone and the other highly vulnerable structures scattered throughout the area. For social and economic vulnerability, the high density and increasing population is a concern, as well as vulnerable households who may not have the economic capacity to cope when disaster strikes, and those with vulnerable members, such as those with disabilities, chronic sickness, female heads, and children and the elderly. Related to emergency management is how to improve the mobility in the site, given the narrow and often blocked roads. The need for evacuation areas and temporary shelter is a concern given that twenty percent (20%) of the structures in the area have more than 10 people living inside.

8. FORMULATING THE RISK REDUCTION OBJECTIVES

The planning process needs to consider explicit objectives for both reduction of disaster risk and improvement of emergency management capabilities. The objectives constitute the main drivers behind the re-development solution. For this purpose the following risk reduction objectives were formulated:

1. There should be no permanent human settlement in structures with a "Very High[4]" Vulnerability rating. All structures located on or within 15 meters from the fault are considered to have very high vulnerability.
2. Structures with "High Vulnerability" rating should be further studied to ascertain their vulnerability level.
3. There should be a voluntary seismic retrofitting program for structures rated as "High Vulnerability", supported by an incentive package and awareness program.
4. The acquisition of structures/lots for open space should be clustered around structures with Very High and High Vulnerability to minimize the number of displaced households.
5. Critical facilities such as schools and health facilities as well as structures which can be used for post-emergency centers should be identified and seismically retrofitted or replaced depending on a benefit/cost analysis.
6. Infrastructure and critical lifelines (e.g., water, sanitation, power, communication, etc.) should be upgraded for seismic performance as an integral part of the redevelopment plan.
7. No intervention is planned for structures with vulnerability of Moderate to Low. However, households of these structures will be encouraged to participate in the voluntary seismic retrofit program.

9. VULNERABILITY AND RISK ASSESSMENT STUDIES

The evaluation of physical, social and economic vulnerability to the households of Barangay Rizal is core to the redevelopment project. How each of the residents is affected by these criteria is determined from the physical risk survey. The socio-economic surveys provide crucial information to devise the compensation scheme that will need to be put in place for the re-development plan.

The physical vulnerability of individual structures was done through a "Rapid Visual Screening for Seismic Vulnerability of Buildings." This was carried out by means of a "sidewalk survey". Trained engineers from Makati City filled up a data collection form for each structure based on visual observation supplemented by data obtained from the City's engineering office. Special attention was also paid to evaluate liquefaction potential.[5] A total of 1,150 structures covering 44 blocks in Zones 7, 8, 9, and 10 were surveyed. This constitutes around 94 percent of the total number of structures (1,229) in the planning area. A special algorithm was designed to classify the structures into four risk levels: Very High, High, Moderate and Low (see footnote 5).

Vulnerability and Capacity Analysis (VCA) was undertaken to determine the existing conditions that predispose the community to potential socio-economic losses and damages in the event of a disaster. The VCA assessment specifically seeks to identify individuals and households who will be adversely affected by a

[4] Structures with a very high likelihood of collapse or extreme damage to earthquakes.
[5] Liquefaction Susceptibility Report Brgy. Rizal, Makati City, Bijan Khazai, 2009

disaster event, and also identify and assess the capacity of households and the community to respond and recover from a disaster event.

The results of the surveys were shared with the community to raise awareness and for educating the community in risk-sensitive re-development. The results are shown in **Figure 6**.

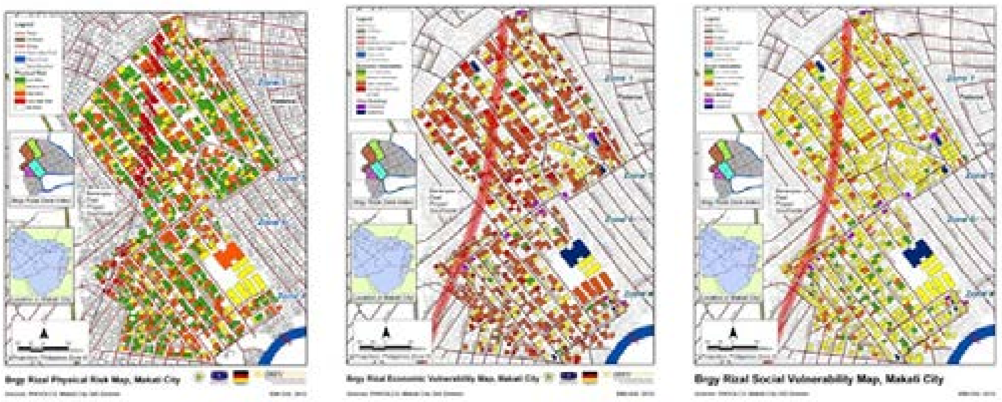

Fig. 6 Results from the Physical, Economic and Social Vulnerability Assessments *(Source EMI, 2010)*

10. THE PROPOSED RISK-SENSITIVE REDEVELOPMENT PLAN

The redevelopment plan is designed for a 10-year timeframe with short term, medium term and long term actions. The priorities in the action planning were driven by the input from the stakeholders and were driven mainly by ensuring community acceptance and developing community trust and support. The redevelopment plan proposes the following interventions:

Fault zone park. An easement zone along the fault needs to be established with access roads on both sides (see **Figure 7**). The access roads will provide the opportunity to redesign new utilities and fire protection systems that considers appropriate earthquake motion. Drainage systems will be incorporated to reduce the risk of flooding. Further, the easement can be used as a park, open market, recreational area, playground, parking space and a community garden. Residents within the fault zone will need to be relocated.

Housing program and pocket open space. New medium density social housing will be provided for the households that will be affected by the redevelopment. The re-housing program should be based on the premise that all relocation will be on-site, i.e., within the Barangay itself.

Retrofit program for high risk structures. A voluntary retrofit program is suggested for structures classified as "High Risk." However, prior to retrofit, more competent structural analysis needs to be undertaken on these structures to ascertain their level of risk considering their construction characteristics and location.

Aside from the abovementioned interventions which directly address physical risk, the following measures are proposed:

Compensation scheme. For those who will be displaced because their existing dwellings are considered to be at very high risk, a compensation scheme that is based on pertinent legal provisions and regulations should be developed.

Incentive program. The voluntary seismic retrofit program needs to be supported by an incentive scheme to favor the engagement of private owners to participate. The incentive scheme can be in various forms such as undertaking all the studies free of charge, providing soft low interest loans, allowing variations in zoning for mixed uses, and others.

Raising Income Level and Improving Economic Conditions. Measures to raise the income and uplift the economic conditions of to reduce the social and economic vulnerabilities include (i) development of neighbourhood commercial centers; (ii) development of educational facilities; (iii) formulation of strategic livelihoods and skills enhancement program and (iv) preparation of business and entrepreneurship support program which includes improving people's access to affordable financing and market linkaging.

Other proposed interventions include: the establishment of development controls and density controls, development of an information education communication (IEC) campaign to improve social acceptability of the project, improvement of circulation network and emergency access, traffic management, open space development, disaster preparedness and emergency management and upgrading of critical infrastructure.

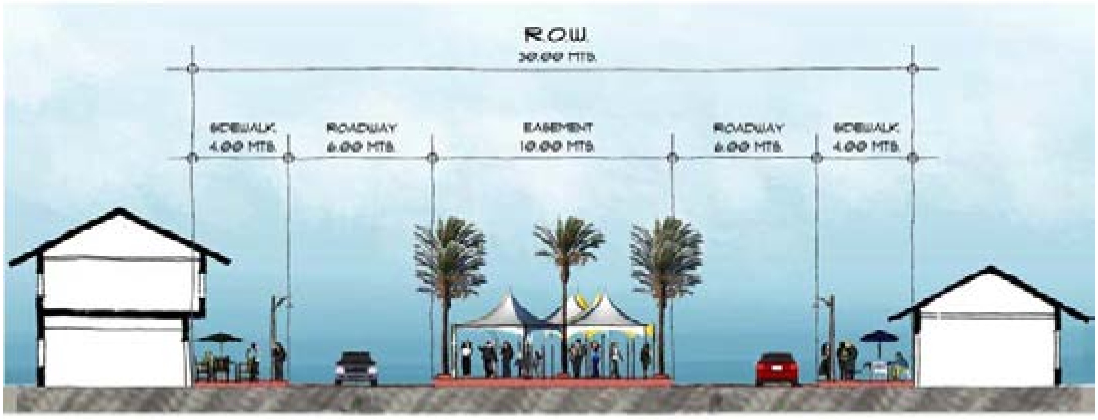

Figure 7. Proposed fault zone park for Barangay Rizal (Source: EMI 2010)

11. CONCLUSION

The project confronted the core issues of mainstreaming DRR in land use planning and urban (re)-development. It doing so, it has to tackle a relatively new area of practice. The project has generated valuable knowledge in terms of both the substantive content and redevelopment planning process for addressing the earthquake risks of a high-risk community. The fact that the project site is virtually all built-up, with small lots and narrow streets, and occupied by predominantly low-income households place extreme limitations on the range of redevelopment options. It was shown that formulating an acceptable redevelopment plan is possible if the planning process is systematic, transparent, participatory and consensus-based. The systematic approach in data gathering, analysis, and presentation at the stakeholder workshops helped significantly in developing a deeper appreciation of the risks that the community faces. A strong multi-disciplinary technical team is needed to collect the detailed data and integrate the many parameters driving the redevelopment while at the same time pursuing the participatory approach. The sensitivity of the City Government representatives and technical experts to the particular culture, socio-economic circumstances, and constraints on the part of the affected households was especially helpful in maintaining a spirit of collaboration and cooperation throughout the planning process. The project demonstrates that land use and redevelopment planning can be powerful tools to lessen the physical, social, and economic vulnerability of high-risk communities.

REFERENCES

Bendimerad, F., Buika, J., Fernandez, J. Mattingly, S., Reyes, M. and Van Boskirk, E., 2007. Urban and Megacities Disaster Risk Reduction: Manual of Sound Practices, Earthquakes and Megacities Initiative Publication. Web reference at: http://www.emi-megacities.org/?page=resources.

Earthquakes and Megacities Initiative, 2008. Mainstreaming Disaster Risk Reduction in Megacities: A Pilot Application in Metro Manila and Kathmandu, Quezon City, Philippines.

Japan International Cooperation Agency, Metro Manila Development Authority, and Philippine Institute of of Volcanology and Seismology, 2004. Metro Manila Earthquake Impact Reduction Study.

German Federal Foreign Affairs Office and EMI, 2010. Risk-Sensitive Urban Redevelopment Plan of Barangay Rizal, Makati City, Philippines, Reports 1 to 5.

Earthquakes and Megacities Initiative, 2007. Evaluation of the 3cd Program Preparatory Phase (2005-2006) Implementation in Metro Manila, 16 Feb. 2007. Web reference: http://www.emi-megacities.org/upload/3cd_2007_02_MMEvalWS_PR0701.pdf.

Earthquakes and Megacities Initiative, 2008. Mainstreaming Disaster Risk Reduction in Megacities: A Pilot Application in Metro Manila and Kathmandu. Quezon City, Philippines.

Earthquakes and Megacities Initiative, 2010. Risk Sensitive Urban Redevelopment of Barangay Rizal, Makati City, Philippines, in Mainstreaming Disaster Risk Reduction in Megacities: A Pilot Application in Metro Manila and Kathmandu. Vols. 1 and 2. Quezon City, Philippines.

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Comparison of Urban Recovery Planning and Designing for Tsunami Hazard between Sanriku Coastal Areas, Japan, and Hilo, Hawaii

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ABSTRACT

Sanriku Coastal Areas, in the northern part of the main land of Japan, survived the catastrophic tsunamis in 1896, 1933, and 1960. The city of Hilo in Hawaii Island also experienced the destructive tsunamis in 1946 and 1960. Having some similarities as tsunami-prone areas, both the areas incurred enormous damage and recovered in their history. However, the post-tsunami urban recovery planning and the future strategy for tsunami management demonstrate differences in both areas. It is important for tsunami disaster management for urban safety to recognize these similarities and differences presented in both areas, and sharing information will be helpful for the future urban planning in the world as well as in both the countries. This paper demonstrates the similarities and differences as follows: (1) outlining both areas' characteristics and those historical tsunami disasters, (2) explaining recovery process after the tsunamis, (3) demonstrating timeline of the tsunami-related events including the aftermaths and the published planning and policies for tsunami disaster management, (4) comparing the contents for urban safety management in recent governments' guidelines and those historical transition in the United States and Japan.

Keywords: the 1896 Sanriku Tsunami, the 1933 Sanriku Tsunami, the 1946 Aleutian Tsunami, the 1960 Chilean Tsunami, post-tsunami urban recovery planning, urban safety planning for tsunami

1. INTRODUCTION

Sanriku Coastal Areas, in the northern part of the mainland of Japan, and Hilo, the second biggest city in Hawaii State in the United States, are both tsunami prone areas. Sanriku Coastal Areas survived the catastrophic tsunamis in 1896, 1933, and 1960, and the city of Hilo experienced the destructive tsunamis in 1946 and 1960. Having some similarities as tsunami-prone areas, exemplified by the fact that both the areas were damaged by the 1960 tsunamis from Chile, both areas

incurred enormous damage and recovered in their history. However, the post-tsunami urban recovery planning and the future strategy for tsunami management present differences in both areas.
Generally, a natural disaster damaged area devises an urban recovery plan to reduce future damage based on the learning from the experience, but its contents and recovery process show diversity according to regional, historical, economical, social, or geographical background. In May 2010, Sanriku and Hilo commemorated the fiftieth anniversary of the 1960 Chilean Tsunami. For the half-century, both areas had been involved in post-tsunami recovery process respectively, and at the same time tsunami-related research had been improved in the United States and Japan. As a result, each country has own idea of the urban safety management for tsunami disaster reduction.
Murao (2010) reported the post-tsunami recovery process in Hilo. Including the contents of the previous report, this paper examines the similarities and differences of urban recovery planning and designing for tsunami hazard presented in both countries because it is important and helpful for the future urban planning to recognize them and to share the information not only for these two countries but also for other needful countries in the world.

2. USED MATERIALS AND METHODS

Although the comparative study has rarely been conducted in a much volume, there are many reports and books covering the tsunamis occurred in Sanriku Coastal Areas and Hilo, so those existing materials are used for the comparative study. In order to arrange the information of Sanriku Tsunamis, the authors refers the books comprehensively written by Yamashita (1982, 1984, 1985, and 1995) and Yoshimura (2004), and the government reports on the 1986 Meiji Sanriku Tsunami (Central Disaster Management Council, 2005) and the 1960 Chilean Tsunami (Central Disaster Management Council, 2010). For the tsunamis in Hilo, the information is obtained from the books written by Dudley and Lee (1988), Dudley and Stone (2000), DOI and USGS (1999), and González and Kamphaus (2000).
The comparative research in this paper is carried out as follows: (1) outlining both areas' characteristics and those historical tsunami disasters, (2) explaining recovery process after the tsunamis, (3) demonstrating timeline of the tsunami-related events including the aftermaths and the published planning and policies for tsunami disaster management, and (4) comparing the contents for urban safety management in recent governments' guidelines and those historical transition in the United States and Japan.

3. OUTLINE OF SANRIKU COASTAL AREAS AND HILO

This section outlines Sanriku Coastal Areas and Hilo as tsunami-prone areas that represent Japan and the United States. Fig. 1 illustrates the locations of cities in both areas, and Table 1 shows deadly tsunamis since the nineteenth century with the number of casualties and maximum tsunami height. Hilo and the cities in Sanriku Coastal Areas are located in the east coast in Hawaii Island and the mainland of Japan facing the Pacific Ocean respectively. Geographically both areas have been influenced by volcanic activities and seismicity that sometimes cause tsunamis. Also these locations are prone to receive tsunamis coming from North and South America, or around the Pacific basin including nearby waters.

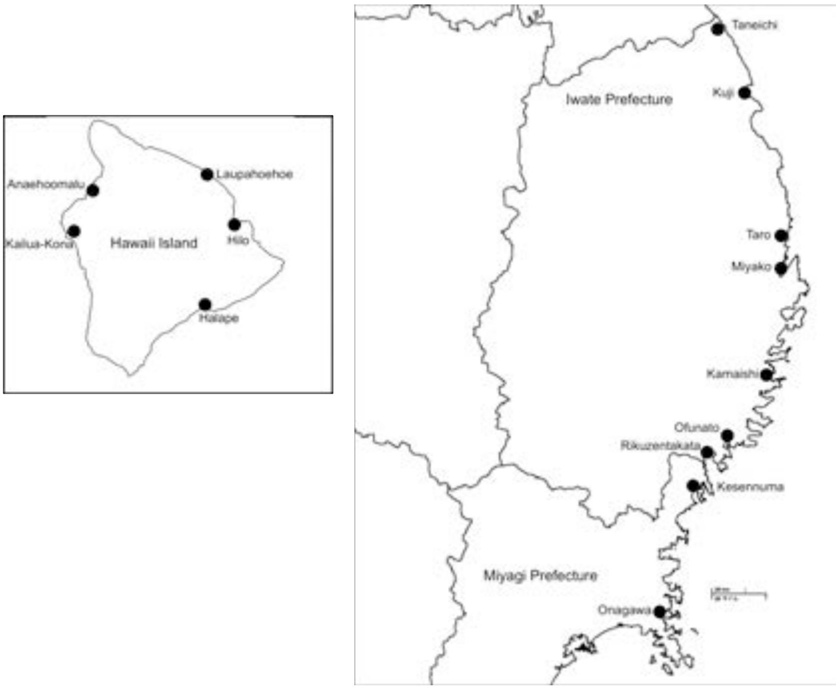

Figure 1: Locations of cities in Sanriku Coastal Areas and Hilo on a same scale

Table 1: Deadly tsunamis and the number of casualties in both areas

		Sanriku Coastal Areas (Yamashita, 1982)		Hilo (DBEDT, 2008)	
Date	Location of Source	Number of Casualties	Maximum Tsunami Height	Number of Casualties	Maximum Tsunami Height
1837.11.7	Chile	-	-	14	6.0m
1877.5.10	Chile	-	-	5	4.8m
1896.6.15	Sanriku Area	app. 22,000	38.2m	-	-
1923.2.3	Kamchatka	-	-	1	6.1m
1933.3.3	Sanriku Area	3,064	28.7m	-	-
1946.4.1	Aleutians	-	-	96	16.4m
1960.5.23	Chile	182	6m	61	10.5m

Hilo is the county seat of Hawaii County and the second-largest city in the State of Hawaii with a population of 40,759 according to 2000 Census of the US. The number of deaths resulting from tsunamis since 1837 in Hilo is 177, and it comprises over sixty percent of those in all of the state. Geographically Hilo faces on the crescent shaped Hilo Bay and spreads on an open plain with gentle slope. The downtown and other residential districts such as Shinmachi and Yashijima had been thrivingly developed in front of the ocean since late nineteenth century until the 1940s, but the tsunamis in 1946 and in 1960 devastated the most of them. The urban recovery process replaced the crowded residential districts into beautiful green belt after 1960.

On the other hand, Sanriku Coastal Areas are known as tsunami hazardous place in Japan, as Koshimura (2005) mentioned: "Judging by the existing materials, it seems that they had tsunamis averagely once per fourty-six years in the history." The most of the town and village communities along the coast of 300km long, from Onagawa in Miyagi Prefecture to Taneichi in Iwate (Figure 1), experienced several catastrophic tsunamis. The number of damaged towns and villages in Miyagi and Iwate by the 1896 Tsunami was approximately fifty-four, and the death-toll ranged from 111 for to 6,986. The number of "shuraku" communities, the minimum jurisdiction unit with a population of hundreds in the region, was approximately 250. Today, there are seventeen municipalities in the coastal areas resulting from municipal mergers after the World War II. Geographically, Sanriku is rias coast, so most of the districts have steep slopes or cliffs behind. However, spatial characteristics of districts show diversity: some are surrounded by mountains in all directions except ocean; others are open to nearby villages. These geographic characteristics directly influenced regional development through post-tsunami recovery process in the areas.

4. TSUNAMI DAMAGE AND URBAN RECOVERY IN THE AREAS

4.1 Making of Timeline

This section gives chronological accounts of tsunami-related events in both areas using the timeline shown as Table 2. It marks tsunamis, recovery activities, aftermaths, tsunami management, and issue of planning and policies for tsunami disaster management in both countries.
In general, a catastrophic urban disaster influences its post-disaster recovery and related disaster management in the next generation. Therefore, the authors classify the time of about 150 years in Table 2 into five periods divided by significant events respectively: (J1) before the 1896 Meiji Sanriku Tsunami, (J2) after the 1896 Meiji Sanriku Tsunami, (J3) after the 1933 Showa Sanriku Tsunami, (J4) after the 1960 Chilean Tsunami, and (J5) after the publication of *Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention* (NLA et al., 1997) until today for Sanriku Coastal Area in Japan; (H1) downtown development era before 1941, (H2) after making of *Master Plan of the City of Hilo*, (H3) after the 1946 Aleutian Tsunami, (H4) after the 1960 Chilean Tsunami, and (H5) after the publication of *Designing for Tsunamis* (NOAA et al., 2001).

Table 1: Timeline table of tsunamis and urban recovery in Sanriku Coastal Areas (Japan) and Hilo (the US)

Year	Events in Sanriku Coastal Areas (Japan)	Events in Hilo (the United States)
1854	The Ansei Toukai/Nankai Earthquake and Tsunami (320+713) [J1]	[H1]
1858	Embankment and planting in Hiro, Wakayama, to reduce tsunami damage	
1868		The 1868 Great Earthquake and Tsunami in Hawaii (47)
1877		**The 1960 Chilean Tsunami** (5)
1888	*Tokyo City and Ward Transformation Act 1888*	
1896	**The 1896 Meiji Sanriku Tsunami** (**app. 22,000**) [J2] Sanriku Coast Railway Project (not realized) 43 communities (7 as organized groups) relocated to higher land, but most of them returned	

1899		The Hilo Railway (Hawaii Consolidated Railway) opening
1908		Breakwater for Hilo Bay commenced
1919	*The City Planning Act/Law 1919*	
1920		The first radio news program broadcasted
1923	The 1923 Great Kanto earthquake (109)	The 1923 Kamchatka Earthquake and Tsunami (1)
1925	The first public radio broadcast delivered	
1929		Breakwater for Hilo Bay completed
1933	**The 1933 Showa Sanriku Tsunami** (**3,064**) [J3] *Guideline to Prepare for Tsunami Disaster* The 10th Anniversary of the Great Kanto Earthquake: The Memorial Project	Tsunami warning given after the earthquake in Sanriku, Japan, but not satisfied
1934	Building Regulation by Miyagi Pref. Call for slogan on the monuments for the future Recovery Plan by Ministry of Home Affairs Planting of tsunami control forest	
1936	Tsunami observation tower constructed in Kamaishi	
1941	Tsunami warning organization established for Sanriku Coast	*Master Plan of the City of Hilo* [H2]
1944	The 1944 Tounankai Earthquake and Tsunami (1,223)	
1946	The 1946 Nankai Earthquake (app. 1,400): The embankment in Hiro worked well	**The 1946 Aleutian Tsunami** (**96** +63) [H3]
1948		Pacific Tsunami Warning Center created following the 1946 Tsunami
1949	*Disaster Rescue Team Regulation* in Kochi Pref. *Systematic Tsunami Forecast and Information Transmission Plan* approved, and exercised	Official tsunami warning capability in the U.S. start at Honolulu Geomagnetic Observatory
1951	The 1st tsunami warning given	
1952	The Tokachioki Earthquake and Tsunami: The Tsunami Warning System worked	**The 1952 Kamchatka Earthquake and Tsunami** (0)
1957		**The 1957 Aleutian Tsunami (0)**: Buildings damaged, but no death toll because PTWS worked
1958	*Coastal Conservation Facility Construction Guideline* established	
1960	**The 1960 Chilean Tsunami (182)** [J4] Disaster dangerous area and building regulation designated in Hamanaka Town in Hokkaido	**The 1960 Chilean Tsunami (61)** : [H4] The system of warning sirens changed, People confused Hawai'i Redevelopment Agency established Coastal development with expansion of buffer zone and landfill considered
1961	The Chilean Earthquake and Tsunami Disaster Countermeasure Project (Policy, Contents, Tsunami breakwater plan…) The 1st tsunami breakwater in the world constructed in Ofunato Hazardous district designated in Nagoya City by Waterfront Disaster Hazardous District and Building Act	
1964		**The 1964 Alaska Earthquake and Tsunami** (0): Partially inundated
1965		*Kaiko'o Project*
1966	Emergency Taskforce for the Chilean Tsunami dissolved	
1967		West Coast & Alaska Tsunami Warning Center (WC/ATWC) established
1968	**The 1968 Tokachioki Earthquake and Tsunami** (53): No mentionable damage in Sanriku Coastal Area because of the constructed breakwaters	The Intergovernmental Coordination Group for the Pacific Tsunami Warning System (ICG/PTWS) established The National Flood Insurance Program (NFIP)
1969	*The City Planning Act/Law 1969*	
1972		*The 1972 Coastal Zone Management Act* (CZMA)
1974		*Hilo Downtown Development Plan* approval
1975		The 1975 Hawaiian Tsunami (2)
1977	Estimated Tsunami Inundation Map released in Sizuoka Pref.	
1979	Submarine Earthquake Observation System Start (JMA)	
1983	*Proposition of Guideline for Systematic Tsunami Disaster Management for Tsunami Hazardous Areas* (MC and JFA) The 1983 Nihonkai-Chubu Earthquake and Tsunami (104)	
1984	Karakuwa Tsunami Museum open	
1985		*Downtown Hilo Redevelopment Plan* approval (Chapter 27:Flood Control of the Hawaii County Code)
1991		The 1st Evacuation maps for Hawaii published
1993	The 1993 Hokkaido Nanseioki Earthquake and Tsunami (200)	
1994	Network of Earthquake Observation System for Urgent Disaster Warning of Earthquake and Tsunami (JMA)	The Pacific Tsunami Museum established
1997	*Tsunami Disaster Estimation Manual* [J5] *Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention* (NLA et al.)	State Emergency Alert System (EAS) start

1998		The Pacific Tsunami Museum open
1999	Tsunami forecasted area expanded and estimation accuracy improved (JMA)	
2001		*Designing for Tsunamis* [H5]
2003	The 2003 Tokachioki Earthquake and Tsunami (2)	
2004	*Tsuami and Tidal Wave Hazard Map Making Manual* (MLIT) Local Governments' tsunami hazard map release ratio on the Internet: 9.6%	EnVision Downtown Hilo 2025 start
2005	*Guideline for Management of Tsunami Evacuation Buildings* (CAO) Systematic Emergency Drill for Wide Area Tsunami exercised (MLIT)	
2006	Improvement of tsunami warning system using the Earthquake Early Warning System (JMA) Local Governments' tsunami hazard map release ratio on the Internet: 34.9%	
2008		*Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*

Tsunamis that damaged to Sanriku Coastal Areas and Hilo are expressed in bold type, and death tall is shown in parentheses.

4.2 Tsunamis and urban recovery in Sanriku Coastal Areas

The time before the 1896 Sanriku Tsunami [J1] was a conventional age in which tsunami phenomena had not been scientifically explained. After the 1854 Ansei Earthquake and Tsunami, an embankment was built and pine trees were forested in Hiro, Wakayama, in order to reduce future tsunami damage, yet the effectiveness had not been judged until the 1946 Nankai Earthquake.

After the 1896 Sanriku Tsunami [J2], consideration was given to relocation to higher land in many damaged villages, but most of it was lead by influences in the communities or was conducted individually. As a result, 43 communities moved to higher places, but most of the residents returned to the previous land because of conveniences for fishery. Besides high land relocation, evacuation route and tsunami control forest were proposed, but they were not realized in the period. In 1925, the first public radio broadcast was delivered, and it became a leading means for tsunami warning in the twentieth century.

In the period of [J3] after the 1933 Showa Sanriku Tsunami, national and local governments' support system basis established even though it was not enough. Scientific basic strategy for post-tsunami recovery was proposed in *Guideline to Prepare for Tsunami Disaster*. Consequently tsunami control forest was planted and reinforced piers were constructed. After World War II, tsunami mitigation facilities such as seawalls were constructed in some places, and tsunami-warning system started in the 1950s.

In the period of Japanese rapid economic growth after the 1960 Chilean Tsunami [J4], urban physical environment for tsunami mitigation such as seawalls and breakwaters were constructed, and related land use regulations were carried out in many places in Japan. In the 1970s, several software for tsunami disaster management, for example tsunami inundation maps, tsunami information systems, and educational activities, was developed in addition to physical environmental countermeasures. As a result of the thirty-year tsunami experience after the Chilean Tsunami, *Tsunami Disaster Estimation Manual* and *Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention* (NLA et al., 1997) were published to show comprehensive tsunami management. It was a new gate into contemporary era [J5], in which hazard maps and tsunami evacuation buildings have been planned and realized in many coastal areas in Japan.

4.3 Tsunamis and urban recovery in Hilo

Urban fabric of Downtown Hilo formed in the early twentieth century [H1] after Kingdom of Hawaii was overthrown in 1893. In this thriving period, the Hawaii Consolidated Railway was opened, and construction of the breakwater for maritime safety commenced.
In the early 1940s, *Master Plan of the City of Hilo* (Territorial Planning Board, 1941) was published. Herein, tsunami related matter was not contained, but urban effectiveness of replacement of waterfront residential districts by a green belt was pointed out. This suggestion probably may affected the urban development after the two great tsunamis in Hilo (Murao, 2010).
The 1946 Aleutian Tsunami damaged to many buildings along the coast. In the recovery period [H3], the government banned building construction along the waterfront to prevent future damage and to create urban green belt. However, some houses were rebuilt in the district to be destroyed by the 1960 Chilean Tsunami again. As well as Japan, some tsunami mechanism were scientifically elucidated in the period, and it triggered tsunami warning system operation.
After the 1960 Chilean Tsunami [H4], which devastated waterfront districts again, beautiful waterfront green belt was realized by Kaiko'o Project. Also, the fact that pacific coast areas were influenced by the tsunami caused the establishment of the Intergovernmental Coordination Group for the Pacific Tsunami Warning System. In the 1990s, State Emergency Alert System started, and Tsunami Museum opened as a tsunami education center.
Recently [H5], systematic idea of tsunami disaster management such as *Designing for Tsunamis* (NOAA et al., 2001) has been proposed and been realized in coastal areas in the US.

5. COMPARISON OF URBAN RECOVERY PLANNING AND DESIGNING FOR TSUNAMI HAZARD

5.1 Scheme of urban Recovery planning and designing for tsunami

This section demonstrates differences of basic tsunami management concept and history between the US and Japan based on materials published by both governments. In order to think up a scheme, *Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention* (National Land Agency et al., 1997) for Japan and *Designing for Tsunamis* (NOAA et al., 2001) for the US are used. The scheme is chronologically classified into four basic stages in the disaster life cycle, (1) mitigation, (2) preparedness, (3) emergency response, and (4) recovery and reconstruction, with a sub stage (5) early warning.
Table 2 shows comparison of history of urban recovery planning and designing for tsunami hazard in both countries based on the concept. The vertical axis demonstrates related items chosen by the two guidelines in the five stages, and the horizontal axis arranges critical materials published by governments or important events.

Table 2: Comparison of history of urban recovery planning and designing for tsunami hazard in Sanriku Coastal Areas (Japan) and Hilo (the US)

Phase	Topic	Subtopic	Item	J1	J2		J3			J4			J5			H1		H2	H3		H4	H5
				Embankment and planting in Hiro, Wakayama	Recovery after the 1895 Meiji Sanriku Tsunami	The Memorial Project of the 1923 Kanto Earthquake	*Guideline to Prepare for Tsunami Disaster*	Recovery after the 1933 Showa Sanriku Tsunami	Tsunami warning organization for Sanriku Coast	Recovery after the 1960 Chilean Tsunami	Estimated Tsunami Inundation Map in Sizuoka	*Guideline for Systematic Tsunami Disaster Management*	*Guideline to Strengthen Tsunami Disaster Management*	*Tsuami and Tidal Wave Hazard Map Making Manual*	*Guideline for Tsunami Evacuation Buildings*	Breakwater for Hilo Bay completed	Tsunami warning given, but not satisfied	*Master Plan of the City of Hilo*	Recovery after the 1946 Aleutian Tsunami	Pacific Tsunami Warning Center created	*Kaiko'o Project*	*Designing for Tsunamis*
				1858	1896	1933	1933	1934	1941	1961	1977	1983	1997	2004	2005	1926	1933	1940	1946	1948	1965	2001
Mitigation	Landuse	Landuse Regulation	Buffer Zone				○	#	>	>	>	○	○	>	>			○	#	>	#	○
			Building Regulation				○	#	>	#	>	○	○	>	>				#	>	#	○
			Relocation to Higher Land		#	>	○	#	>	○	>	○	○	>	>				#	>	#	○
			Planning in Inundation Area							#	>	○	○	>	>			○	>	>	#	○
	Construction Forestation	Avoiding	Elevated Buildings																#	>	#	○
			Elevated Construction																			○
		Slowing	Tsunami Control Forest	#	#	>	○	#	>	○	>	○	○	>	>						#	○
			Ditches																			○
			Slopes																			○
			Berms																			○
			Blocking Walls																			○
		Steering	Location of Walls																			○
			Angled Walls																			○
			Ditches																			○
			Paved Surfaces																			○
		Blocking	Breakwater		#	>	○	#	>	#	>	○	○	>	>	○			X			○
			Seawall	#	#	>	○	#	>	○	>	○	○	>	>				X			○
			Walls							#	>	>	>	>	>							○
			Levee							○	>	○	○	>	>							
			Water Gate							#	>	○	○	>	>							
			Compacted Terraces and Berms		#	>	>	#	>	#	>	○	○	>	>						#	○
			Tsunami Resistant Buildings									○	○	>	>							
			Parking Structures																		#	○
		Reinforcement	Piers				○	#	>	○	>	○	○	>	>						#	○
			Earthquake Reinforcement		X		○	○	>	○	>	○	○	>	>							○
			Tsunami Reinforcement				○	#	>	○	>	○	○	>	>				#	>	>	○
			Industrial Facilities							○	>	○	○	>	>						#	○
			Building Design Guideline in terms of functions									○	○	>	>						#	○
			Existing Building Reinforcement									○	○	>	>							○
Preparedness	Damage Estimation											○	○	>	>							○
	Disseminate of Risk Information		Damage Estimation									○	○	>	>							○
			Hazard Map								#	○	○	○	>						#	○
			Evacuation Map									○	○	○	>						#	○
	Education & Edification									○	>	○	○	>	>						#	○
	Tsunami Memorial											○	○	>	>							
	Organization for Disaster Management											○	○	>	>							
	Emergency Drill											○	○	>	>							

Early Warning	Observation											○	○	>	>						#	○
	Warning System								#	○	>	○		>	>		●			#	#	○
Emergency Response	Task Force											○	○	>	>							
	Evacuation	Horizontal	Evacuation Route		#	>	○	#	>	○	>	○	○	>	>						#	○
			Evacuation Area				○	>	>	○	>	○	○	>	>						#	○
		Vertical	Evacuation Route												○							○
			Construction of Evacuation Buildings												○							○
			Designation of Evacuation Buildings												○							○
		Sign										○	○	>	>						#	○
		Care for the disabilities										○	○	>	>							
Recovery and Reconstruction	Systematic Concept																					○
	Commemoration Project				X	#	○	#	>	#	>	○	○	>	>						#	>

#: realized, ○: planned or proposed, ●: realized but not satisfied, X: planned but not realized, >continued

5.2 Comparison of urban recovery planning and designing for tsunami hazard in the US and Japan

Although we can discuss several topics based on the Table2, the two references, which are used for the scheme, are compared here. Both materials contain hardware and software for tsunami management, but those descriptions for structural aspect of buildings are different. The followings are three examples.

Firstly, unlike *Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention*, in *Designing for Tsunamis*, "there are four basic site planning techniques that can be applied to projects to reduce tsunami risk: 1) avoid inundation areas, 2) slow water currents, 3) steer water forces, [and] 4) block water forces," and it systematically and concretely explains how physical environment should be prepared to mitigate tsunami damage.

As for evacuation, *Designing for Tsunamis* divides it into two types, vertical and horizontal. Probably, it was so natural for people in Sanriku Areas to evacuate toward high land through steep hills because their living place was located along rias coast that they were not conscious whether it was vertical or horizontal. On the other hand, the evacuation in Hilo meant horizontal because of its flat geography.

Third example is the meaning of monument. Construction of memorial after a disastrous event is common as well as wars, but it is to the memory of it in the US as exemplified by Laupahoehoe monument; it is to enlighten or to educate people to mitigate future disaster with aphorisms like "escape after shaking" in Japan.

6. CONCLUSION

This paper demonstrates the similarities and the differences of post-tsunami urban recovery and tsunami management between Sanriku Coastal Areas and Hilo using timeline. The timeline is classified into five chronological phases separated by critical tsunamis or important events for urban safety planning respectively: the 1896 Sanriku Tsunami, the 1933 Sanriku Tsunami, the 1960 Chilean Tsunami, and the year of the Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention published by Japanese Government in 1997 for Sanriku Coastal Areas; the year of 1940 Master Plan of the City of Hilo, the 1946

Aleutian Tsunami, the 1960 Chilean Tsunami, and the year of Designing for Tsunamis published by FEMA et al. in 2001 for Hilo. The timeline and the comparative study of the contents for urban safety management clearly illustrate how both the countries had struggled and evolved the urban strategies for tsunamis since 1894.

ACKNOWLEDGEMENTS

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REFERENCES

Central Disaster Management Council, 2005. *Report on the 1986 Meiji Sanriku Earthquake and Tsunami*, Cabinet Office, Government of Japan, http://www.bousai.go.jp/jishin/chubou/kyoukun/rep/1896-meiji-sanrikuJISHINTSUNAMI/index.html (in Japanese).

Central Disaster Management Council, 2010. *Report on the 1960 Chilean Earthquake and Tsunami*, Cabinet Office, Government of Japan, http://www.bousai.go.jp/jishin/chubou/kyoukun/rep/1960-chile%20JISHINTSUNAMI/ (in Japanese).

The Department of Business, Economic Development & Tourism, State of Hawaii, 2008. *2008 State of Hawaii Data Book Individual Tables* , http://hawaii.gov/dbedt/info/economic/databook/2008-individual/.

Dudley, W. C., and Lee, M., 1998. *Tsunami ! (2nd ed.)*. Honolulu: University of Hawai'i Press.

Dudley, W. C., and Stone, S. C. S., 2000. *The Tsunami of 1946 and 1960 and the Devastation of Hilo Town*, Virginia Beach: Donning.

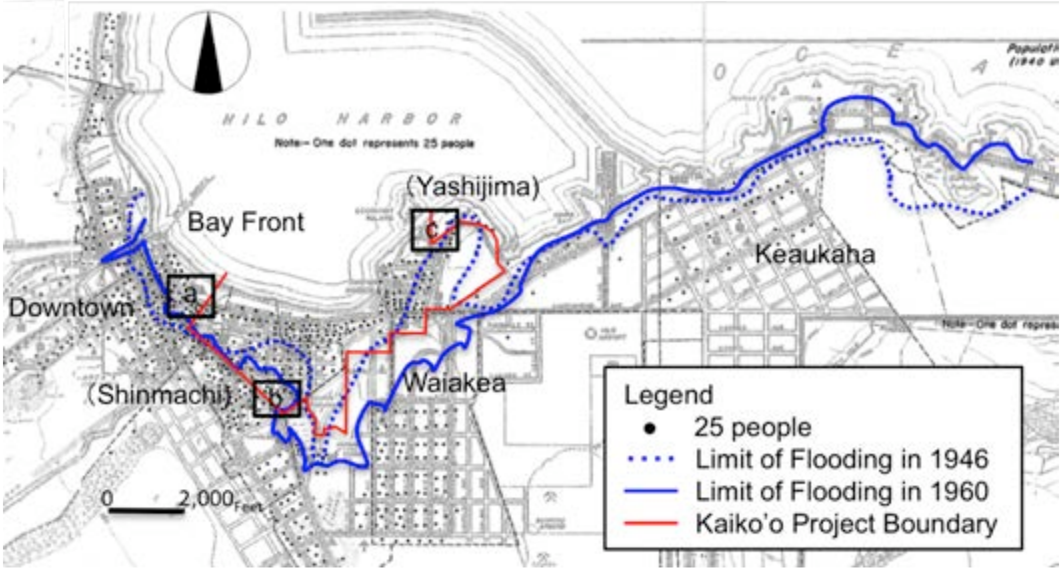
González, F., and Kamphaus, R., 2000. *May 2000 Tsunami Inundation Mapping Progress Report*, http://nthmp-history.pmel.noaa.gov/may00.pdf.

Koshimura, S., 2005. Chapter 1: Outline of Tsunami Disaster in Sanriku Region, *Report on the 1986 Meiji Sanriku Earthquake and Tsunami*, Central Disaster Management Council, Cabinet Office, Government of Japan, http://www.bousai.go.jp/jishin/chubou/kyoukun/rep/1896-meiji-sanrikuJISHINTSUNAMI/index.html, 3 (in Japanese).

Murao, O., 2010. Post-Tsunami Urban Recovery Plan and Recent Situation in Hilo, Hawaii: On-site Report on the 50th Anniversary of the 1960 Chilean Tsunami, *Reports of the City Planning Institute of Japan*, No.9-1 (CD-ROM), 12-17 (in Japanese).

National Land Agency et al., 1997. *Guideline to Strengthen Tsunami Disaster Management in Local Plan for Disaster Prevention*.
NOAA et al., 2001. *Designing for Tsunamis Seven Principles for Planning and Designing for Tsunami Hazard*, http://nthmp-history.pmel.noaa.gov/Designing_for_Tsunamis.pdf.
Territorial Planning Board, Territory of Hawaii in collaboration with County Board of Supervisors County of Hawaii, 1941. *Publication No.9 December 1940 Master Plan of the City of Hilo, County of Hawaii, Hawaii*. Honolulu: Advertiser.
U.S. Department of the Interior and U.S. Geological Survey, Compiled by Atwater, B. F., Cisternas V., M., Duldley, W. C., Hendley, J. W. II, and Stauffer, P. H., 1999. *Surviving a Tsunami–Lessons from Chile, Hawaii, and Japan*, U.S. Geological Survey Circular 1187. United States Government Printing Office.
Yamashita, F., 1982. *Sorrowful History of Sanriku Great Tsunamis* (*Aishi Sanriku O-Tsunami*), Seijisha (in Japanese).
Yamashita, F., 1984. *Record of Photograph of Modern Tsunami History in Japan* (*Shashin Kiroku -Kindai Nihon Tsunami-shi*), Seijisha (in Japanese).
Yamashita, F., 1985. *Disaster Management Lecture -Knowledge of Tsunami-* (*Bousai Kouza -Tsunami no Kokoroe-*), Seijisha (in Japanese).
Yamashita, F., 1995. *The 100th Anniversary of the Meiji Sanriku Tsunami -The Great Meiji Sanriku Tsunami with Pictures-* (*Meiji Sanriku Hyaku shunen Kinen -Shasin to E de Miru Meiji Sanriku O-Tsunami-*) (in Japanese).
Yoshimura, A., 2004. *The Great Tsunamis in Sanriku Coastal Areas* (*Sanriku Kaigan O-Tsunami*), Bungei Shunju (in Japanese).

APPENDIX



Tsunami Inundation Limits in Hilo (Dudley and Lee, 1998) and Population Distribution as of December 1940 (Board of Supervisors County of Hawaii, 1941)

Present Situation in Hilo

A Study on Flood Disaster Mitigation by Local Government Regulation and Guidance in Japan

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ABSTRACT

In Japan, in preparation for large-scale flood, municipalities are legally obligated to make and publish "Flood Hazard Map" for evacuation from flood. In the short term, the improvement of evacuation is important. At the same time, it is needed to reduce the vulnerability of city to flood from a long-term perspective because it is estimated that climate change will increase the occurrence frequency of flood in the future. Though flood risk control should be considered in the process of urban planning, the concept of flood control has been lacked in Japanese urban planning system. However, some municipalities implement urban planning regulation and guidance for flood disaster mitigation.

Through the Internet and literature search, ten cases were picked up. The authors had interviews to the administrative officers of ten cases and qualitatively evaluated the effect and problem of each case. In this study, it is found that municipalities are negative to introduce regulation for flood disaster mitigation because they hesitate to impose a burden to citizens, and it is difficult to establish the standard for regulation. The effect of guidance and subsidy is limited to the part of citizens. The role-sharing among river administrators, municipalities and citizens is needed to improve flood risk management in urban planning.

Keywords: flood disaster mitigation, urban planning, flood hazard map, climate change adaption measures

1. INTRODUCTION

In Japan, flood countermeasures have been mainly held by building water works like dams and levees to completely prevent floods since the River Law was established in 1896. However, recent some floods in urban area like the Fukuoka Flood Disaster in 1999, Tokai Flood Disaster in 2000 were wake-up call to remind that the countermeasures were needed in preparation for flood disaster. The Flood Prevention Law revised in 2003 and 2005 obligates municipalities to make and publish flood hazard map on rivers which would damage the municipality in case of flood. Flood hazard map shows the estimated flooded area, the estimated flood depth and the location of refuges in case of a specific large-scale flood.

In the short term, it is important to improve evacuation planning by flood hazard map. At the same time, it is also needed to reduce the vulnerability of city to flood from a long term perspective because climate change will increase the occurrence frequency of large-scale flood in the future. Though flood risk control is should be considered in urban planning process, the concept of flood risk control has been lacked in Japanese urban planning system. However, some municipalities implement urban planning regulation and guidance for flood disaster mitigation.

The purposes of this study are as follows: 1) to investigate the actual situations of municipal regulation and guidance for flood disaster mitigation, 2) to qualitatively evaluate the effect and problem of each case and 3) to discuss the condition for developing flood risk control in urban planning.

2. CASE STUDY

Through the Internet and literature review, the ten cases of municipal urban planning regulation and guidance for flood disaster mitigation were searched. Interviews were conducted on the municipal officers in charge of ten cases. The cases are classified into four types depending on implementation systems (Table 1).

Table 1: Investigated cases in this study

Implementation type	Municipal regulation and guidance
Regulation	Nagoya City Building Ordinance
Guidance	Setagaya City Building Guideline
	Suginami City Building Guideline
	Shinjuku City Building Guideline
Regulation and guidance	Kusatsu City Building Ordinance
Subsidy	Nakano City Subsidy to High-floored Building
	Suginami City Subsidy to High-floored Building
	Shinagawa City Subsidy to Flood Protection Shield
	Suginami City Subsidy to Flood Protection Shield
	Komaki City Subsidy to Flood Protection Wall

2.1. The case of flood disaster mitigation by municipal regulation

2.1.1. The outline of the building ordinance in Nagoya City

In 1959, the storm surge of Isewan typhoon broke down coast and river levees causing ruinous damages to Nagoya city. The dead and disappeared were 1,851, the afflicted people were 530,000, and the damaged houses were 118,000 in the city. Learning from the Isewan typhoon disaster, Nagoya City established a building ordinance in 1961 to introduce flood disaster mitigation in preparation for the case that coast and river levees were breached by storm surge or river flood. This building ordinance is based on a provision of Building Code, “designation of disaster risk zones”, which legally enables a municipality to designate disaster-prone areas as disaster risk zones and to establish building restrictions on the area. Nagoya City Building Ordinance is the only case in Japan that flood disaster mitigation is implemented in a vast urban area by the designation of disaster risk zones.

Table 2: The restrictions of Nagoya City Building Ordinance

District		Ground floor Height	Structure
1st	− Harbor area − Outside of tidal barrier	N.P. +4.0m	Wooden construction is banned.
2nd	− Urbanized area − In danger of deep flooding	N.P. +1.0m	A room must be established on second floor and above.
3rd	− Urbanized area	N.P. +1.0m	
4th	− Urbanization-restricted area	N.P. +1.0m	A room must be established on second floor and above.

(Source: Nagoya City)

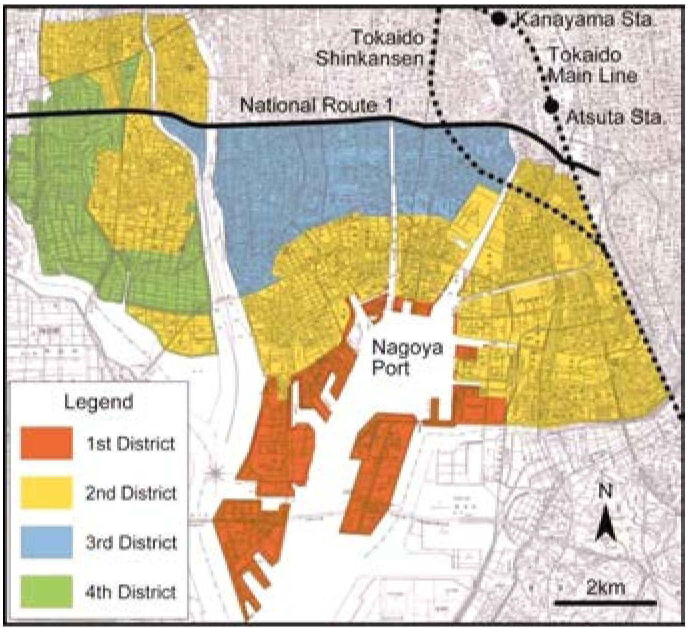

Figure 1: Four districts of Nagaya City Building Ordinance (Source: Nagoya City)

The area in application of Nagoya City Building Ordinance extends 6,000ha. The area is classified into four districts depending on the estimated flood damage and the land use situation. The regulations on ground-floor level and building structure are established on each district (Table 2, Figure 1). The aim of this regulation is to secure safety refuges for saving human lives in case of large-scale flood including storm surge.

The 1st district is in danger of being swept away by storm surge because this district is located outside tidal barriers. Hence, in the 1st district, the ground-floor level of building must be higher than N.P.[1] +4m, and wooden structure is basically banned to build.

In the 2nd, 3rd and 4th districts which are located inside tidal barriers, the ground-level of building must be higher than N.P. +1m. The 2nd district is estimated to be deeply flooded by storm surge. In the 4th district, since it is urbanization-restricted area, buildings are so scattered and safety refuges are few. Hence, safety evacuation spaces are needed to be secured in individual buildings. For these reasons, making a room on second-flood and above is obligated in the 2nd and 4th district. In the 3rd district, restriction on building structure is not imposed because this district is located inland, and it is estimated to be not deeply flooded comparing with other districts.

Additionally, in the 2nd, 3rd and 4th district, the building ordinance puts further restrictions on public buildings like schools, hospitals, community centers and government offices which are refuges in case of flood disaster. The restrictions are as follows: 1) the ground-floor level must be higher than N.P. +2m, 2) one or more rooms must be established higher than N.P. +3.5m and 3) wooden structure is banned to build.

The observance of restrictions is verified in the process of building certification base on Building Act. Correction order is given to the building when the restrictions are violated. The punishment based on Building Act is applied in case that the correction order is also neglected.

2.1.2. Effect and problem

The effects of Nagoya city building ordinance are as follows: 1) the safety level in the area has been improved up to now in preparation for the breach of flood barriers and dikes by storm surge, and 2) the building ordinance leads to the enlightenment for promoting further flood disaster mitigation than the restrictions.

On the other hand, it can be said that the ordinance has already fulfilled a roll appropriate to the needs of the times after Isewan typhoon. The ground floor height of building is settled in the ordinance, but it is not strict comparing with ground level. Additionally, the most of recent buildings are higher than two-story. Another ordinance appropriate to current situation is needed for developing further flood disaster mitigation.

Another problem of the building ordinance is that some flood disaster mitigation measures are not suitable for barrier-free building. For example, raising ground-floor makes the length of wheelchair ramps longer.

2.2. The cases of flood disaster mitigation by municipal guidance

2.2.1. The outline of municipal guidance cases

The number of flood damage to basement room by local heavy rain has increased for these years. For this reason, Setagaya, Suginami and Shinjuku City in Tokyo established each building guideline for flood damage mitigation. These guidelines aim to inform building owners on flood risk and flood damage mitigation measures.

These cities employ the notification procedure as the following. In the process of building certification, the owner who will construct a building shown in table 2 is supposed to turn in a document for showing the type and the extent of measure which is employed for flood damage mitigation. In Suginami City and Shinjuku City, the notification procedure is applied to the area which would be flooded according to the flood hazard map of each city.

Table 2: The target of notification procedure

<table>
<tr><th></th><th>The target of notification procedure</th></tr>
<tr><td>Setagaya Building Guideline
(2005~)</td><td>New-built or rebuilt building
− which has a floor under the surrounding ground or road,
− or in which discharge water might flow back because of the surroundings</td></tr>
<tr><td>Suginami Building Guideline
(2005~)</td><td rowspan="2">New-built or rebuilt building
− which is located in the flood-hazard area shown on the flood hazard map,
− and which has possibilities of flood due to locating lower than the surrounding ground or road</td></tr>
<tr><td>Shinjuku Building Guideline
(2009~)</td></tr>
</table>

(Source: Setagaya, Suginami and Shinjuku City)

These cities advise the owners to mound up the entrance to basement, put in a mobile flood protection shield or a drainage pump and so on. However, the extent of flood mitigation measure is left to the owner’s choice in all of these guidelines.

The owners are not legally obligated to employ a flood mitigation measure because these guidelines are not based on any law. These cities are making efforts so that flood mitigation measures are devised on the target buildings through guidance.

2.2.2. Effect and problem

The targets of the building guidelines are limited to the part of buildings, but they have functions to inform flood risk and promote flood mitigation measures in the process of urban planning. If an owner does not employ the appropriate flood mitigation measure following the guideline, it is important that this system gives the owner the information on flood risk and an opportunity to make a decision whether the owner employs flood mitigation measure.

2.3 The case of the combination of regulation and guidance

2.3.1. The case of building ordinance in Kusatsu City

Kusatsu City is located in Shiga Prefecture, and facing Biwa Lake which is the largest lake in Japan. Some ceiling rivers are running through the city. This city had suffered from floods of Biwa Lake and ceiling rivers. After river improvement work was recently completed, large-scale flood has never occurred in Kusatsu City. However, in 2006, Kusatsu City established a building ordinance for promoting flood disaster mitigation in reaction to the publication of the flood danger area maps of Biwa Lake and some rivers in 2002 or later. This ordinance doesn't have legal obligation because it is not based on any law.

In this building ordinance, the estimated flooded area and the estimated flood depth are shown on one map which is made by overlapping the flood danger area maps of Biwa Lake and some rivers. The depth in the map is the deepest water level in the flood danger area maps (Figure 2).

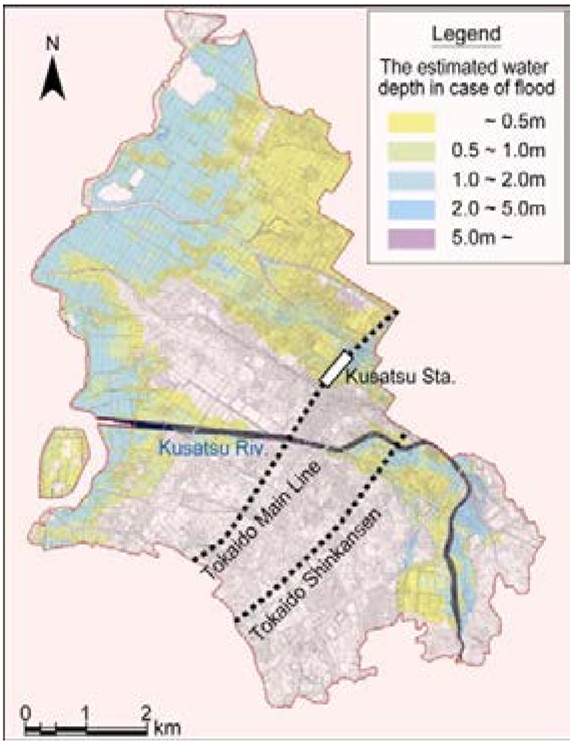

Figure 2: The areas in danger of being flooded (Source: Kusatsu City)

Disaster-prevention facilities and refuges are designated "specific building" in the building ordinance. When a specific building is built, it is obligated to employ flood mitigation measure considering the estimated flood depth shown on the map. The specific buildings are mainly public buildings like government office, school and hospital. Hence, the regulation on specific buildings is implemented as self-imposed regulation of public sector.

Notification procedure is employed in regard with ordinary buildings. The owner who will build a building with a basement or an emergency elevator is supposed to turn in a document for showing a flood mitigation measure employed in the process of building certification. However, the owner is not obligated to employ flood mitigation measure in the same way as Setagaya, Suginami and Shinjuku City.

2.3.2. Effect and problem

Kusatsu City is preparing for large-scale flood by introducing flood mitigation measure into disaster-prevention facilities and refuges considering the flood depth shown on the flood danger maps. It leads to securing the function of disaster-prevention facilities and refuges in case of flood. In regards to ordinary buildings, though the target is limited, it is important that the guidance based on the ordinance gives the owner the information on flood risk and an opportunity to make a decision whether the owner employs flood mitigation measure in the same way as Setagaya, Suginami and Shinjuku City.

2.4. The cases of flood disaster mitigation by municipal subsidy

2.4.1 The cases of subsidy to high-floored building

In 1970's, floods of rivers running through urban area occurred frequently in the west part of Tokyo because river improvement work did not catch up with the speed of urbanization. For this reason, Nakano and Suginami City started the subsidy device to build a house which of the ground-floor is elevated above ground level. Afterward, the subsidy device was abolished once because the number of subsidies decreased. However, in September 2005, heavy rain caused flood damage to both of the cities. Nakano and Suginami City restarted the subsidy each in 2005 and 2008.

Nakano City gives the subsidy to the owner who will construct or reconstruct a building in the areas which have flooded since 1981 and which is still danger of being flooded because of the delay of river improvement work. Additionally, Nakano City eased the height regulation of building on the subsidy object area. Nakano City will downscale the subsidy object area following the progress of the river improvement work.

Table 3: The standard price of subsidy to high-floored building

Construction method, structure type		Standard price (yen/m^2)
Elevation of existing building		78,000
New construction	Wooden construction	55,000
	Steel construction	42,000
	Reinforced concrete structure	29,000

(Source: Nakano and Suginami City)

Suginami City gives the subsidy to the areas which would be flooded higher than 0.5m in Suginami City Hazard Map in addition to the areas which have flooded so far. Suginami City will continue the subsidy regardless of the progress of the river improvement work.

In both of Nakano and Suginami City, the given subsidy is half the amount multiplying the high-floored space (m^2) by the standard price (yen/m^2) shown in table 3. However, the limit is 2,000,000 yen in both of them.

Nakano City had given 101 cases by May 2009, but Suginami City had never given subsidy at the time of December 2009. Comparing the number of subsidy with the occurrences of flood damage in Nakano City, it is found that the number of subsidy increases soon after flood damage, but afterward gradually decreases.

2.4.2. The cases of subsidy to flood protection shield

Shinagawa City, in Tokyo, started the subsidy to mobile flood protection shields in 1989 because floods of rivers running through the city frequently caused damages in 1980's. Shinagawa City gives the subsidy to the building owner and user who will establish the shields on house, store and office. This subsidy aims to cover the delay of the flood control measures in the city. According to the officer of Shinagawa City, it will be abolished at the time when flood control measures are improved and flood damages are solved.

Suginami City started the subsidy to mobile flood protection shields in 2008 in addition to the subsidy to high-floored houses. Suginami City gives the subsidy to the building owner and user who will establish the shields. Suginami City will also continue the subsidy regardless of the river improvement work.

Table 4: The subsidy to flood protection shield

	Subsidy content
Shinagawa City	To person: 3/4 of the expense for flood protection shield To company: 1/2 of the expense for flood protection shield However, the limit is 1,000,000 yen.
Suginami City	1/2 of the expense for flood protection shield However, the limit is 500,000 yen per one building.

(Source: Shinagawa and Suginami City)

By May 2009, Shinagawa City had given 119 cases, and Suginami City had given 3 cases. Comparing the number of subsidy with the occurrences of flood damage in Shinagawa City, it is found that the number of subsidy increases soon after flood damage, but afterward gradually decreases in the same way of the subsidy to high-floored houses in Nakano City.

2.4.3. The case of subsidy to flood protection wall

Komaki City, in Aichi Prefecture, have offered subsidy to flood protection wall since 2006. It is impossible to completely prevent flood damage by river or sewage improvement in regard with the buildings which are located lower than the surrounding roads or water channels. The subsidy aims to mitigate flood damage on those buildings.

2.4.4. Effect and problem

The effects of subsidies for flood disaster mitigation are as follows: 1) citizen's self-motivated flood damage mitigations are promoted, and 2) the flood damages on small spots which are lower than the surrounding roads or water channels can be individually managed.

Generally, the number of subsidy gets increased soon after flood damages, but the flood damage mitigation by subsidy is not developed after a certain period of time. It is pointed out that the people who employ flood mitigation measure getting subsidy are almost those who got damaged by flood.

Additionally, the flood damage mitigation by subsidy is apt to be conducted as municipal measure which covers the delay of river improvement work. For developing flood mitigation measures from long-term viewpoint, municipalities have to reconsider the role of the subsidy for flood damage mitigation and put forward flood risk information with the subsidy.

3. DISCUSSION

From the results of case studies, the condition for developing flood risk control in urban planning will be discussed below.

Flood disaster mitigation employing the designation of disaster risk zones like Nagoya City Building Ordinance raises a safety level of whole the designated area because the targets of regulation include all buildings. Additionally, it is effective from a viewpoint of implementation because the ordinance is based on Building Code. However, except Nagoya City, no municipality introduces the designate of disaster risk zones into vast urban area. As a result of interviews to the municipal officers, the municipalities are negative to introduce the regulation flood disaster mitigation because of the following reasons: 1) they hesitate to impose a burden to citizens, and 2) it is difficult to establish the standard for regulation.

The reason why Nagoya City could introduce the designation of disaster risk zones is considered that Isewan typhoon convinced both the government and the citizens the necessity of flood disaster mitigation. At the same time, it is found that the standard of flood disaster mitigation was determined from the result of Isewan typhoon disaster.

Currently, flood hazard map is published, but citizens are not familiar with the maps because flood risk itself is not enough shared in society. In this current situation, like Kusatsu, Setagaya, Suginami and Shinjuku City, informing flood risk in the urban planning process is effective. In those cities, however, the target is limited to the part of buildings. Flood risk information should be informed to more persons concerned like building owners, users, constructors and designers. For example, the system that the flood risk and mitigation measure on building must be informed to customer is conceivable. Like Kusatsu City, flood mitigation measures on disaster-prevention facilities and refuges should be also implemented by regulation.

Up to now, in Japan, the responsibility for countermeasure to large-scale flood beyond flood control facility has never been discussed. For developing flood risk management in urban planning, flood risk should be shared in society, and the role-sharing among river administrators, municipalities and citizens needs to be discussed and clarified.

NOTES

1. N.P. ±0m is the water level of Nagoya Port at the time of low tide.

REFERENCES

Katada, T., Kimura, S., and Kodama, M., 2007. Desirable utilization of flood hazard maps for risk communication. Doboku Gakkai Ronbunshu D, Vol.63, No.4, p.p.498-589 (Japanese)

Panel on Infrastructure Development, 2008. Climate change adaptation strategies to cope with water-related disasters due to global warming, Ministry of Land, Infrastructure, Transport and Tourism

Building Research Institute, Ministry of Construction, 1960. The investigation of urban area and building damage in Nagaya City by Isewan Typhoon and the disaster prevention plan, Nagoya City (Japanese)

Study on Town Development Rules Considering Disaster Reduction and Neighborhood Characteristics in Densely-Built Areas, Process of Town Planning in Shonai Area, Toyonaka City

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ABSTRACT

In the Hanshin Awaji Great Earthquake on 17 January 1995, fires which broke out in and around Nagata and Hyogo wards caused severe damage. In Japan, there still are many densely-built residential areas and the fire disaster prevention ability in such areas should be improved as soon as possible. In this study, therefore, a model of town development rules is examined from the perspectives of both "disaster reduction" and "neighborhood characteristics" through a case study in Shonai area, Toyonaka, Osaka prefecture. In examining disaster reduction, authors named one of the methods to reduce disaster damage in the area using fire blocking belts as "Roadside Method" and the other to increase the disaster prevention performance of each building as "Individual Method", then compared the disaster prevention performance of the current town and two virtual towns, each using one of the two methods, by fire-spreading risk assessment. The results indicated that structural reform can be quicker and more realistic than widening roads in the enhancement of the disaster reduction performance in a densely-built area. The neighborhood characteristics of a "normal densely-built residential area" were grasped by survey on the views and wishes of the residents. The results suggested that a townscape created by either "Roadside Method" or "Individual Method" should be accepted unless the buildings are rebuilt into ones which are too high relative to road width. Regarding the space in front of buildings, many people found bicycle parking undesirable while planting was considered most "desirable". When combined with planting, however, bicycle parking became more acceptable. Following the above mentioned factors, a model of town development rules considering disaster reduction and neighborhood characteristics is proposed.

Keywords: *densely-built residential area, town planning, fire spreading risk, disaster prevention performance, neighborhood characteristic*

1. INTRODUCTION

1. 1 Background and Purpose of the Study

In the Hanshin Awaji Great Earthquake on 17 January 1995, fires which broke out in and around Nagata and Hyogo wards caused severe damage. In Japan, there still are many densely-built residential areas and the fire disaster reduction ability in such areas should be improved as soon as possible.

After the Great Earthquake, therefore, improvement projects have been promoted in urban areas where wooden houses are densely built. Apart from some special areas such as preservation districts for groups of traditional buildings, such improvement projects in "ordinary densely-built residential areas" often exclusively focus on "disaster reduction performance" neglecting "neighborhood characteristics". It is important in these areas, however, to preserve "neighborhood characteristics" . The "disaster reduction performance" also, however, cannot be understated.

In this study, therefore, the purpose is to propose a set of model town development rules considering both disaster reduction and neighborhood characteristics in a "ordinary densely-built residential areas".

1.2 Study Method

Through a case study in Shonai area, Toyonaka, from the perspectives of both "disaster reduction" and "neighborhood characteristics", a set of model town development rules in a densely-built residential area was examined in order to find a way for it to include both goals.

Possible methods of securing disaster reduction in a densely-built residential area were examined and applied to virtual towns, then fire spreading risk was assessed by the physical fire spreading predicting model for urban fires, developed by Himoto(2007) and Akimoto(2008).

The elements of the neighborhood characteristics in a densely-built residential area were examined. The method of securing disaster reduction were taken in consideration, to determine "Shonai-like, favorable elements from a survey on what the residents think and wish.

2. FIRE SPREADING RISK ASSESSMENT

2.1 Outline of the Subject Area

In Shonai area in Toyonaka, Osaka, the case study area of this research, there still remain constructions unsafe in a disaster as a result of rapid urbanization with the urban infrastructure such as roads and parks left inadequate in the period of rapid economic growth in the 1960s. There are also many small lots of about $50m^2$, which makes it difficult for the houses to be rebuilt.

On the other hand, it is an area where town development has been proceeded since the 1970s with the participation of residents. Three residential environmental improvement projects have been implemented and currently the resident-led town development is in progress in S area with the Town Development Committee as the center, utilizing the Project for Actors for Plan Making in Town Development promoted by the Ministry of Land, Infrastructure, Transport and Tourism.

2.2 Methods to Secure Disaster Reduction in Densely-Built Areas

In the current regional plan in the S area in Shonai, Toyonaka city, the case study area, the enhancement of the disaster reduction ability of a zone along the highways and main community roads with fire blocking belts is considered to enhance the disaster reduction ability in the entire area.

Figure 1: Regional plan in Shonai area, Toyonaka city (draft)

However, whilst fire blocking belts enhance the disaster reduction ability in the area as a whole, the risk of fire spreading in high-risk densely-built residential areas may not decrease sufficiently.

In this study, therefore, authors named the method to reduce disaster damage in the area using fire blocking belts as "Roadside Method" and another method to increase the disaster prevention performance of each building as "Individual Method", then compared the disaster prevention performances of virtual towns, each using one of the two methods, by fire-spreading risk assessment.

2.3 Town Conditions

Eight virtual towns of Shonai area, the subject of the case study, were created based on above-mentioned "Roadside Method" and "Individual Method" as well as over time. Along with the condition of the actual town, fire-spreading risk is assessed for a total of nine town conditions.

Table 1: Conditions for Fire-Spreading Risk Assessment

Category	Details	Conditions
A	Current Town	Current condition
B1	Roadside method (with 40% of buildings in the area improved)	Virtual
B2	Roadside method (with 60% of buildings in the area improved)	Virtual
B3	Roadside method (with 80% of buildings in the area improved)	Virtual
B4	Roadside method (with 100% of buildings in the area improved)	Virtual
C1	Individual method (with 40% of buildings in the area improved)	Virtual
C2	Individual method (with 60% of buildings in the area improved)	Virtual
C3	Individual method (with 80% of buildings in the area improved)	Virtual
C4	Individual method (with 100% of buildings in the area improved)	Virtual

First of all the risk was assessed for A, with the current conditions. Then for B, in a virtual town where the Roadside Method, which has now been planned in Shonai, the risk was assessed. Lastly the virtual cases where the Individual Method is applied were examined, then the effectiveness of the Roadside Method and the Individual Method were studied by comparison with the current conditions.

Regarding B and C, the effectiveness of each one were compared by assessing the cases from B1 to B4 and from C1 to C4 with the improvement of 40%, 60%, 80% or 100% respectively according to the rules, taking the time passage into the consideration.

2.4 Definition of Fire-Spreading Risk

In this study, the concept of fire risk has been introduced and essential fire safety capacity existing in an urban area was assessed as a fire-spreading risk in the fire-spreading simulation. In general, fire risk R is defined as a product of loss possibility P and loss L, or the expected loss, as below.

$$R \equiv \sum_{i=1}^{N} \left(P_i L_i \right) \qquad (1)$$

In this study, in order to assess the fire-spreading risk by individual buildings, the loss possibility P is defined as the possibility that an individual building would be involved in a spreading fire, and loss L as whether or not each building is destroyed in each run. Also, taking the scale of an urban fire into consideration, the number of buildings destroyed in the 12-hour period after the outbreak of the fire is counted. The simulation was run 500 times.

2.5 Conditions for Calculation

The area of the S area, the subject in this case study, is approximately 8.7 ha. Uncertain factors for risk assessment are the conditions of fire breakout and weather. The conditions at the time of the start of the fire, such as the location and time of the fire breakout, were randomly chosen. For the weather conditions, the outside temperature and wind direction and speed were considered. Expanded

AMeDAS Weather Data was used for creating the input conditions which matched the randomly chosen time of a fire breakout.

2.6 Building Conditions

n the fire spreading simulation in this study, four categories were set for the building structures, namely wooden structure, fire-proof wooden structure, semi-fire-proof structure and fire-proof structure. The fire spreading characteristics for each structure are shown below.

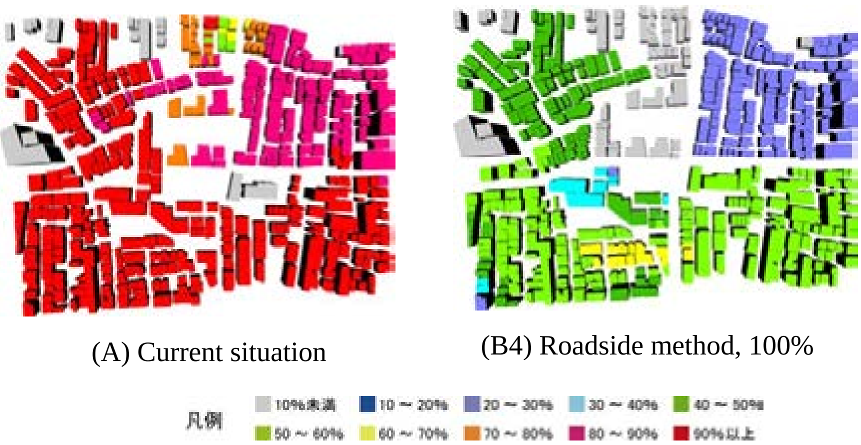
Table 2: Fire Spreading Characteristics by Structure

	Unit	Wooden	Fire-proof wooden	Semi-fire-proof	Fire-proof
Time to burn through (openings)	min	10	10	20	20
Time to burn through (walls)	min	20	30	45	No burning through

2.7 Calculations, Result and Analysis

2.7.1 Comparison between A and B4

The comparison between A, the area of the current situation and B4, the virtual town with the Roadside Method with 100% of buildings improved is shown in Figure 2. The widening of main community roads and the area alongside the roads as a fire blocking belt are apparently effective. The northeast bloc, in particular, benefits from the fire blocking belt.

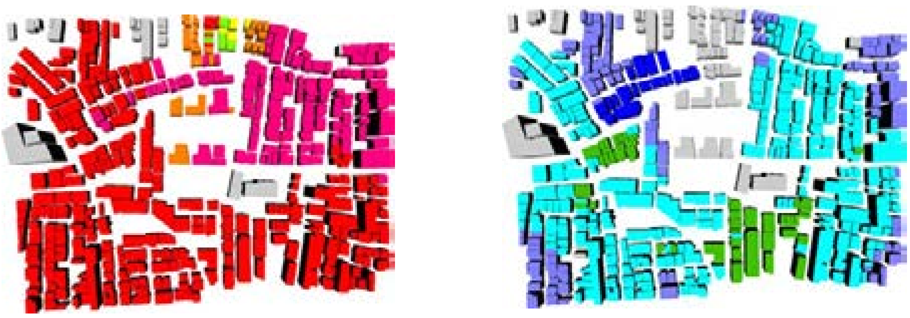


(A) Current situation (B4) Roadside method, 100%

Figure 2: Comparison between A and B4

2.7.2 Comparison between A and C4

The comparison between A, the area of the current situation and C4, the virtual town with the Individual Method with 100% of buildings improved is shown in Figure 3. The fire spreading risk greatly decreased from the current situation, but there are some differences according the blocks. This is probably because some places have more factors to stop fires such as open spaces than other blocks.

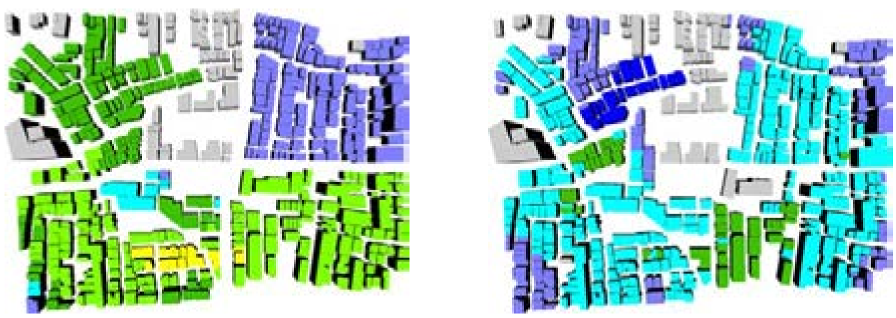


(A) Current situation (C4) Individual Method, 100%

Figure 3: Comparison between A and C4

2.7.3 Comparison between B4 and C4

The comparison between B4, the virtual town with the Roadside Method with 100% of buildings improved, and C4, the virtual town with the Individual Method with 100% of buildings improved is shown in Figure 4. Fire spreading risk is higher with Roadside Method as a whole, which is thought to be because the influence of fire spreading within the residential area is bigger than the effect of stopping fires within a block by the fire blocking belt.



(B4) Roadside Method, 100% (C4) Individual Method, 100%

Figure 4: Comparison between B4 and C4

2.7.4 Comparison between B and C over Time

Comparison between B, virtual towns with Roadside Method and C, virtual town with Individual Method is shown in Figure 5.

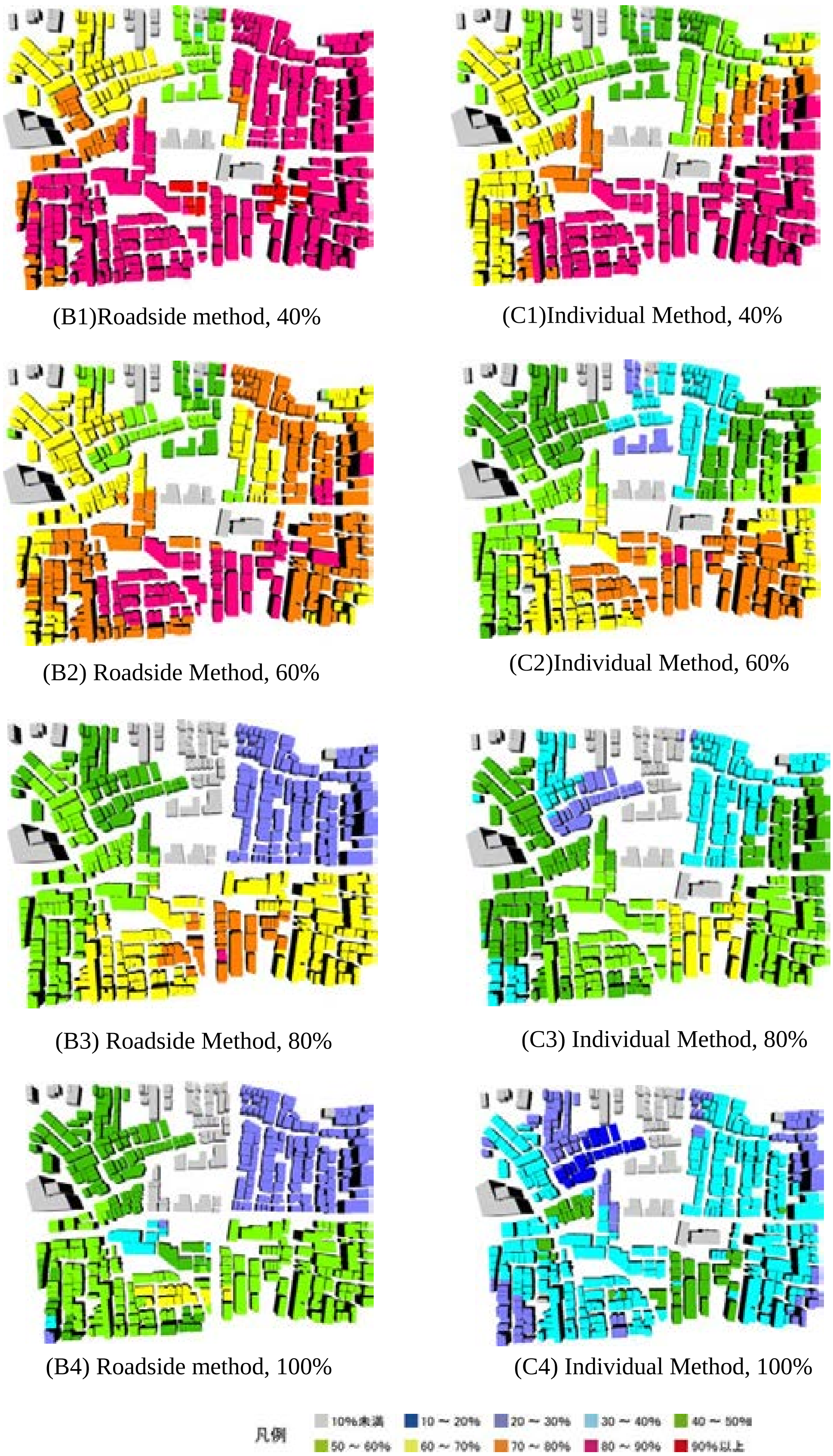


Figure 5: Comparison between B and C over Time

In either case of Roadside Method or Individual Method, when 100% improvement takes place, certain effects can be seen though different in features. It is, however, many decades away that all the buildings will actually be improved and, from a practical point of view, more immediate measures are required. The comparisons over time indicate that Individual Method starts working at an earlier stage, whilst Roadside Method makes a difference only when the fire blocking belt is completed to a certain level.

These results suggest that structural reform can be quicker and more realistic than widening roads in the enhancement of disaster reduction performance in a densely-built area.

3. SURVEY ON THE VIEWS AND WISHES OF THE RESIDENTS

3.1 Purpose of the Survey

As mentioned in 1.1, it is important to consider both disaster reduction and neighborhood characteristics in an "ordinary densely-built residential area" in the process of town development.

So, a hypothesis was formulated about the components of the neighborhood characteristics, based on which a questionnaire was made to survey the views and wishes of the residents. This was done in order to find out what elements the residents in Shonai area find as "Shonai-like" and "favorable", then to formulate "Shonai-like, favorable elements".

3.2 Survey Method

The survey was conducted in S area, Shonai, Toyonaka-city, the subject area of this case study, on the local residents who participated in "Our Town's Rules Workshop" , by asking them to respond to a 30-item questionnaire during the workshop.

Dates: 1 November (10 am and 1 pm), 3 November: total of three times
Subjects: 38 residents who participated in "Our Town's Rules Workshop" (including members of the Town Development Committee)

3.3 Contents of Survey

As the elements of the neighborhood characteristics in a densely-built residential areas, a hypothesis was formulated with two categories of "townscape" and "space in front of building" as follows.

A. Townscapes

In order to grasp the characteristics of the neighborhood with the two methods of Roadside Method and Individual Method applied, the elements for "townscape" such as " building height (number of stories)" and "road width" were set as below.

A1: Two-story, frontal road with 4m width (+0.5m setback)
A2: Three-story, frontal road with 4m width (+0.5m setback)
A3: Four-story, frontal road with 10m width (+0.5m setback)

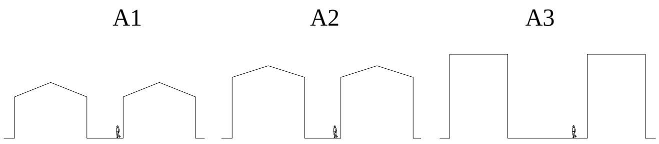


Figure 6: Items of Townscape

B. Frontal Space

For the space in front of a building, items were set as below regarding "walls" "planting" and "bicycle parking", to understand how residents feel and what influences these have on the townscape.

B1: Walls
B2: Planting
B3: Bicycle parking
B4: Planting and bicycle parking

Neighborhood characteristics is represented by a model of combinations of A and B above. One of A or B is fixed to facilitate comparison between combinations such as those between A1B1 and A1B2 or A1B1 and A1B3, etc. Respondents answered 30 questions regarding "Shonai like" and "favorable". The questionnaire is laid out as Figure 7.

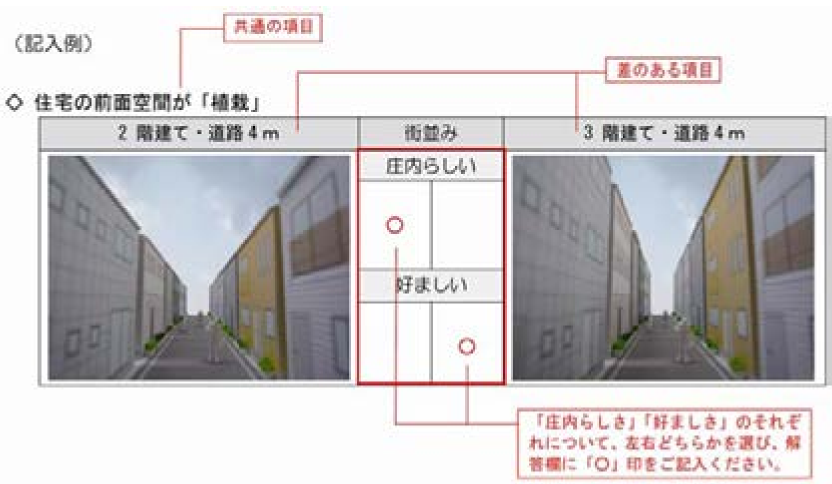


Figure 7: Questionnaire on Neighborhood Characteristics

3.4 Result of Survey

The results of the questionnaire are shown in Table 3 and 4.

Table 3. Result of A, townscape

	Shonai-likeness	Favorability
A1: Two-story, frontal road with 4m width	**239**	**128**
A2: Three-story, frontal road with 4m width	**130**	**81**
A3: Four-story, frontal road with 10m width	**44**	**185**

The results indicated that A1 with two-story buildings and the 4m wide frontal roads is most Shonai-like, while A3 with four-story buildings and 10m wide frontal roads is most attractive.

Table 4: Results of B, frontal space

	Shonai Likeliness	Favorability
B1: Walls	**78**	**97**
B2: Planting	**130**	**212**
B3: Bicycle parking	**172**	**103**
B4: Planting and bicycle parking	**164**	**137**

The results suggested that B3, bicycle parking, is the most Shonai-like, while B2, planting, is the most attractive.

3.5 Analysis

The questionnaire results show that people find low-rise buildings more Shonai-like from the townscape viewpoint, and where the roads are of the same width, the low-rise townscape is preferred. On the other hand, if the roads are sufficiently widened, high-rise buildings are more likely to be accepted. There remain some doubt, however, whether it is equally acceptable to replace buildings with high-rises in the zones along the north-south road with a width of 10m and along the east-west road with a width of 6.7m, since people did not highly regard high-rise townscape with narrow roads in A2.

Regarding the space in front of buildings, people found bicycle parking Shonai-like, but not desirable. The most desirable factor is planting. Combined with planting, however, bicycle parking became more acceptable.

4. CONCLUSION

In this study, a set of model town development rules is examined from the perspectives of both "disaster reduction" and "neighborhood characteristics". The results obtained through the case study indicated what the rules should be like taking disaster reduction and neighborhood characteristics into consideration.

The result of the fire-spreading assessments suggested Individual Method can be better than Roadside Method from the disaster reduction point of view because Individual Method worked at an earlier stage. With the following two factors based on the examination of the neighborhood characteristics, however, it cannot be definitely said that one is better than the other.

1) Roadside Method to widen the main community roads can be appropriate because wider roads are required.
2) Individual Method can be appropriate because people find low-rise townscape Shonai-like and this method does not change the townscape much from the current situation.

Therefore, it is probably desirable for the town development rules to consist of Roadside Method and Individual Method. In other words, while widening the main community roads is one of the goals, basically disaster reduction performance should be secured by reforming all the buildings into semi-fireproof or fireproof structures. Also verticalization is acceptable along a road with a sufficient width, but allowing high-rises to be built along a narrow road by relaxation of district regulations is not desirable.

There is another point that when roads widened and buildings verticalized along the roads the townscape may lose all the Shonai-like features. In order to avoid that as much as possible and to create a "Shonai-like, favorable town", it can be effective to include the usage of the frontal spaces in the town development rules to be proceeded with planting.

REFERENCES

HIMOTO K., TANAKA T., 2007. *Development of a Physics-based Urban Fire Spread Model*, Journal of Environmental Engineering, No.607 (2007), pp.15-22
AKIMOTO Y. 2008. *Study on Fire Safety of Densely-built residential areas Based on Fire Risk Assessment,* Master Thesis, Kobe University.

Understanding Chromium (VI) Transport Through Concrete

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ABSTRACT

Hexavalent chromium [Cr(VI)], a highly toxic carcinogen, rarely occurs naturally but is released as part of waste from chromate ore processing facilities and some other chemical industries. Given its properties, concrete is an excellent candidate for barricading and storing wastes containing hexavalent chromium. However for effective long term performance of such barriers, it should be borne in mind that concrete is a porous material and allows ingress and migration of water and various dissolved ions. It is understood that the rate and extent of such ingress and migration depends on the nature of the pore structure of the concrete matrix, i.e., size, distribution, interconnectivity, shape, and tortuosity of the pores. Previous research has indicated that (i) concrete can sequester Cr(VI) ions, which then become a part of the matrix and this hexavalent chromium does not leach easily, (ii) incorporation of hexavalent chromium in concrete does not adversely affect it's strength and durability.

This study was carried out to contribute to a rational design for concrete barriers for hexavalent chromium. Concretes having a water-cement ratio between 0.4 and 0.7 were used to study Cr(VI) migration including advective transport through micro-cracks, concentration-gradient driven diffusive transport, and uptake and sequestration.

It was found that though concrete with a low w/c and higher cement content showed an ability to sequester more Cr(VI), the actual uptake of hexavalent chromium, was found to depend on both – the intrinsic sequestration capacity and the ease of ingress of ions. Easy ingress of Cr(VI) into concrete with a high water-cement ratio, resulted in an enhanced initial Cr(VI) uptake. However, due to the limited intrinsic ability of this type of concrete to sequester Cr(VI), the uptake rate slowed over time, and eventually, some Cr(VI) breakthrough was also observed.

Keywords: *Hexavalent chromium, concrete, permeability, sequestering, porosity, cement*

1. INTRODUCTION

Though hexavalent chromium [Cr(VI)] rarely occurs naturally, it is released as part of waste from chromate ore processing facilities and certain chemical industries. It is important that efforts are made to ensure that this highly toxic carcinogen [Syracuse Research Corporation, 1993] does not pollute the environment, especially the ground water. Given its properties, concrete is an excellent candidate for barricading and storing wastes containing hexavalent chromium. However for effective long term performance of such barriers, it should be borne in mind that concrete is a porous material and allows ingress and migration of water and various dissolved ions. It is understood that the rate and extent of such ingress and migration depends on the nature of the pore structure of the concrete matrix, i.e., size, distribution, interconnectivity, shape, and tortuosity of the pores, which in turn depend on the properties and proportioning of constituent materials. Though previous research has indicated that (i) concrete can sequester Cr(VI) ions, which then become a part of the matrix and this hexavalent chromium does not leach easily, (ii) incorporation of hexavalent chromium in concrete does not adversely affect its strength and durability. This study was undertaken to contribute to a rational design for concrete barriers for hexavalent chromium by studying properties such as uptake of hexavalent chromium and its diffusion through concrete.

2. EXPERIMENTAL DETAILS

2.1 Overall plan

The overall experimental programme is summarized in Table 1.

Table 1 Overall experimental programme

Series	*Objective*	*Method*	*Remarks*
A	Study uptake of hexavalent chromium by concrete powder	Determining the (a) (increase in) chromium content in concrete powder, and, (b) recording reduction in chromium levels in the solution.	Samples (powder or discs) were obtained from cylinders having a w/c ratio between 0.4 and 0.7, after the concrete had been cured for at least 5 weeks to minimize effects of continued hydration. Samples were then brought in contact with solutions containing Cr(VI)
B	Study uptake of hexavalent chromium by concrete discs	Using (b) outlined for Series A, and estimating the uptake of chromium by the concrete disc.	
C	Study diffusion of hexavalent chromium through concrete discs	Setting up diffusion cells using concrete discs exposed to solution on one side and pure water on the other – allowing diffusion under a concentration gradient. Changes in the chromium concentration in the solution on both sides of the concrete disc was monitored.	

2.2 Materials used

River sand was used as fine aggregate along with 12.5 mm coarse aggregate and OPC [43 grade as per IS 8112, 1989]. Laboratory tap water was used for mixing and curing. Table 2 gives details of the proportions of constituents used for the different concretes.

Table 2 Mix proportions for different concretes (kg/m^3)

Mix	*w/c*	*Water*	*Cement*	*Aggregates*	
				Fine	*Coarse*
C40	40	190	475	486	1249
C50	50		380	549	1281
C60	60		317	606	1287
C70	70		271	659	1279

2.3 Experimental procedure

Preparation of discs and powder: Hardened concrete was removed from moulds after 24 hours and stored under water for 5 weeks, and then 20 mm thick discs were cut using a diamond cutter, discarding the top and bottom 50 mm of the cylinder. These discs were stored under water for until use in experiments. In Series A, the disks were crushed using a pulverizer. Powders were sieved and the fraction passing through 600 μm and retained in 300 μm sieves was stored separately in plastic containers at room temperature until use in further experiments. In Series B, before immersion in solutions of hexavalent chromium, concrete disks were dried at 50°C for several days to completely remove the free water. In the case of Series C, water saturated discs were used without drying.

Preparation of chromium calibration curve: Solutions containing various pre-determined amounts of chromium were prepared. The corresponding absorbance values were determined at 540 nm after addition of 1, 5 di-phenyl di-carbazide using a spectrophotometer. Calibration curves were prepared for two ranges of chromium mass – 1 to 5 μg and 5 to 20 μg, using cuvettes of 4 cm and 1cm path length, respectively, for the two ranges.

Uptake by concrete powder: 2g of powder was accurately weighed and placed in 40ml glass vials and 25 mL aliquots of 5 mg/L Cr(VI) solution was added to each vial, which was sealed and placed on the orbital shaker for mixing. Vials were removed sequentially from the shaker after 2, 4, 6, 8, 10, 15, 20 and 25 hours of contact times with the chromium solution. The samples were then filtered and the residue (concrete powder) with adsorbed Cr(VI) was dried in an oven for 24 hours at 50^{o}C, and preserved for further analysis. The filtrate was also analyzed for residual Cr(VI).

Uptake by concrete disks: The disks were dried and placed in plastic containers containing 800 mL of 5 mg/L Cr(VI) solution, taking care that there is no evaporation. The concentration of Cr(VI) in the solution was monitored with time to estimate the uptake by the concrete disks.

Diffusion cell: A specially designed cell as shown in Figure 1 consisting of two compartments – one containing 20 mg/L Cr(VI) solution and the other containing pure water, separated by a concrete disk, was used for the purpose. The discs used

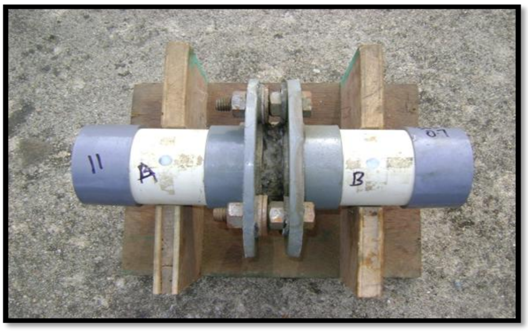


Figure 1 Diffusion cell used

in this series were initially saturated with water to ensure that only ionic diffusion occurred and any effect of water movement *per se* was minimized. Holes in both compartments served as sample ports. Every 15 days, a sample of 2 ml was drawn from compartment A and 2 ml of pure water containing no Cr(VI) added before resealing the sampling port. This ensured that the volume of liquid in the compartment remained the same throughout the experiment. Similarly, 50 ml samples were drawn from compartment B at regular intervals and an equal volume of pure water added as replacement.

3. RESULTS AND DISCUSSION

3.1 Hexavalent chromium uptake in powdered concrete

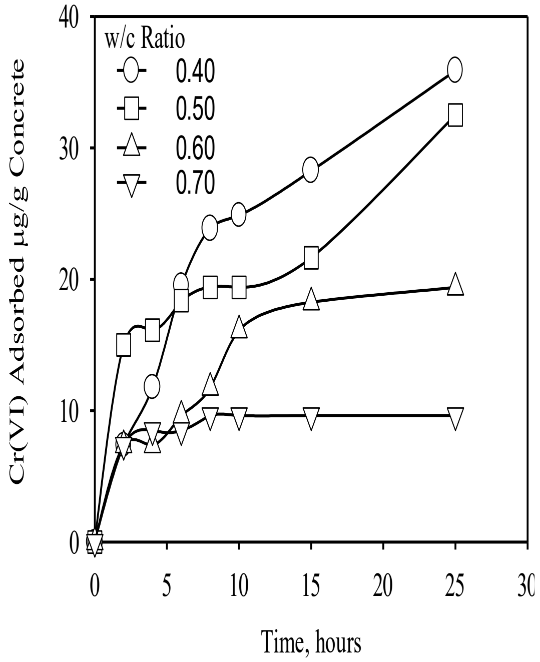
Results for the uptake of hexavalent chromium as a function of the contact time (varied between 2 and 25 hours) as described above are shown in Figure 2. It is apparent that in all cases the uptake increases with the contact time and decreases with the increase in the w/c ratio of the concrete. The uptake is essentially complete after 10 and 25 hours for concretes C70 and C60, respectively, while in the other two cases, the uptake continues to increase even after 25 hours of contact.

3.2 Hexavalent chromium uptake in concrete discs

The results on the basis of uptake by dry concrete disks immersed in Cr(VI) solutions estimated from the reduction in the chromium concentration in the solution, are plotted in Figure 3. Comparison of chromium uptakes by powder and the disc suggests *(i)* rate of Cr(VI) uptake by concrete disks was much slower than that by concrete powder, *(ii)* Cr(VI) uptake by C70 and C60 concrete over 30 days, was found to be about 5 to 7 μg Cr(VI) adsorbed per gram concrete, compared to a lower value of about 1 to 2 μg in the case of concretes C50 and C40.

3.3 Hexavalent chromium migration in diffusion cell

In all cases, a drop from the initial Cr(VI) concentration in compartment A (initially 20 mg/L) was observed, though the extent and rate of this drop was found to be related to the w/c of the concrete of disc. The actual uptake by the discs of concrete C40, C50 and C70, as estimated by mass balance of chromium within the system, is shown in Figure 4. It can be seen that though the initial uptake of C70 is higher, the final uptake of C40 and C50 is much higher. Converting this total uptake to a rate of uptake, it was also found that the flux of Cr(VI) into concrete was 1.24 $\mu g/cm^2/d$ for the disks of concrete C70, and, 1.92 and 2.05 $\mu g/cm^2/d$, respectively, in disks of concretes C50 and C40. However though flux was lower for 0.7 w/c ratio disks, it was found that Cr(VI) found its way to compartment B (*breakthrough*) in only about 90 days [Chitnis, 2009].



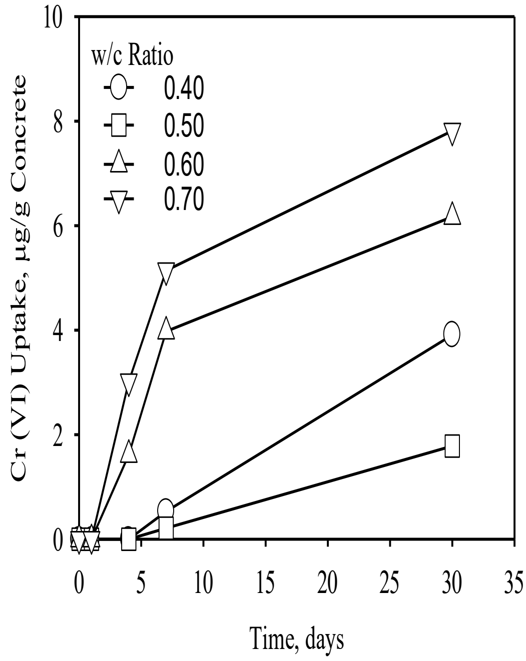


Figure 2 Uptake of chromium by concrete powder (Series A)

Figure 3 Uptake of chromium by concrete disks (Series B)

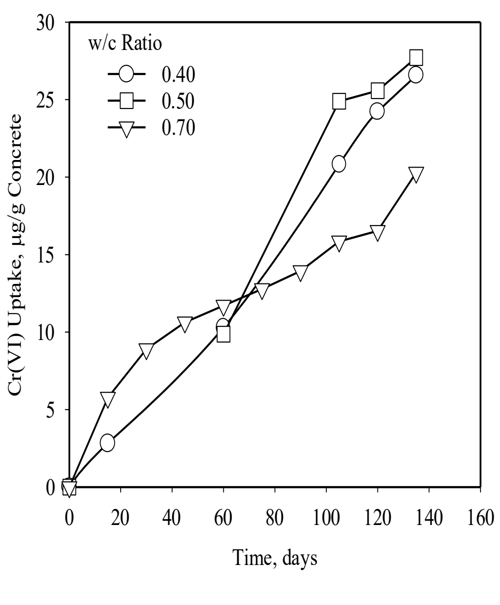


Figure 4 Uptake of chromium by disks in diffusion cells

3.4 Discussion of results

As far as the uptake of chromium by the concrete powder is concerned, it can be summarized that since the specific surface areas of the concrete powders used were nearly the same (all powders having been drawn from between 300µm and 600µm, and having a specific surface area in the narrow range of 2.28 to 3.03 m^2/g), the difference in uptake can be attributed to only the difference in the cement contents of the different concretes, which in this case is directly related to the water-cement ratio (the water content being constant in all mixes) [Palmer, 2000].

In Series B it may be noted that the discs immersed in the chromium solution were initially dry and thus, some initial uptake would be through the water movement into dry concrete and also concentration driven diffusion into the pore solution of concrete at later stages. Further, continued sequestration and adsorption into the hydration products of concrete (similar to uptake in the powder) will also contribute to generating the difference in concentration gradient. Thus the results obtained are the overall result of the two processes. Now, whereas a lower water-cement ratio reduces the porosity of the matrix and uptake due to the former process, it tends to increase the uptake on account of the latter (because of the higher cement content).

In the case of experiments using the diffusion cells in Series C, the uptake process is similar to that in Series B, except that (a) concrete is saturated to begin with and therefore it may be assumed that the uptake through direct movement of water is minimal, and, (b) the uptake takes place only from one face of the disc. Now, the lower final flux in case of disks of concrete C70 may be explained considering the lower intrinsic Cr(VI) adsorption capacity of this type of concrete due to its lower cement content. The breakthrough in this concrete (C70) and also for C60 [Chintis, 2009] can be attributed to the higher porosity of this concrete. Results for discs with other w/c also show that uptake is more for concrete powders with lower w/c ratios (higher cement contents) [Chitnis, 2009].

4. CONCLUDING REMARKS

From the experiments carried out using concrete powders and dry and wet concrete discs made from of different water-cements, it was found that concretes with a higher w/c ratio, due to their higher porosity, allow faster diffusion of Cr(VI) into concrete mass, which facilitates higher Cr(VI) uptake. However, these concretes with limited cement contents have only a limited capacity to sequester any chromium ions that penetrate into the concrete. Thus, these ions continue to move through the pore structure and could breakthrough the concrete thickness. However in the case of concretes with a lower w/c, the porosity being lower, the initial uptake is low, and with the higher sequestration capacity because of a higher cement content, the possibility of breakthrough is also reduced. In other words, in the case of low w/c ratio concrete, which has the intrinsic ability to sequester more Cr(VI), the net uptake of Cr(VI) by such a concrete mass is often limited by low rate of Cr(VI) diffusion into the concrete mass.

REFERENCES

Chintis, NS, 2009, *Understanding Cr(VI) transport through concrete*, M. Tech Thesis submitted to Indian Institute of Technology Kanpur

Palmer, CD, 2000, *Precipitates in a Cr(VI) contaminated concrete*, Environmental Science and Technology, 34, 4185-4192

Syracuse Research Corporation, 1993, *Toxicological profile for chromium*, Report for the US Department of Health and Human Services, Public Health Service, Agency for toxic substances and disease registry, Contract no 20588-0608

Trapdoor tests for the evaluation of earth pressure acting on a buried structure in an embankment

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ABSTRACT

Earth pressures acting on underground structures are highly dependent on the interaction between ground and structure. Increase in the vertical earth pressures acting on a buried structure in high embankment should be, therefore, considered, depending on the size and depth of structure and type of foundation, since differential settlements are often expected in such conditions. However, in practice, the increment of vertical earth pressures on underground structures is estimated in the empirical manner, mainly based on the information of past earth pressure measurements in the limited number of sites. In such estimation, the degree of settlement and/or mechanical properties of backfill materials are not always taken into account. A trap door test apparatus is newly developed in this research, in order to evaluate distribution of earth pressures acting on a buried structure. Detailed measurements were conducted and earth pressure change was estimated by relatively simple calculation.

Keywords: *buried structure, earth pressure, trapdoor test*

1. INTRODUCTION

Vertical earth pressures on a buried structure in an embankment is likely to be increased if the surrounding backfill soil settles, due to the downward shear forces acting on a soil block above the buried structure, as schematically shown in Figure 1. In practice, the increment of vertical earth pressure is estimated, following "General guidelines for road earthworks (1999)", in which the coefficient α, the ratio of initial and increased earth pressure, are proposed as shown in Table 1. The values of α had been determined in the empirical manner, mainly based on the earth pressure measurement records obtained from construction sites in 1980s. They seem to be reasonable estimation, since no serious problem has been recognised so far on the buried structures within standard type embankment construction. However, the detailed mechanism of earth pressure change is not well understood and it may be an obstacle for the rational and economical design of buried structure.

Ebizuka and Kuwano (2009) developed a trapdoor apparatus in order to evaluate the effects of differential settlements on earth pressure distribution on a buried structure. Base of a soil chamber consists of five separated parts, any combination of those can move downward, in order to simulate the uneven settlement. In this paper, overall results of the trapdoor tests are described.

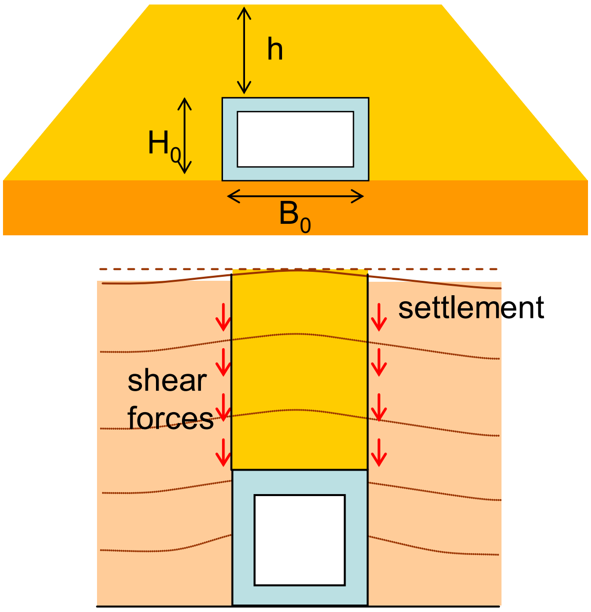


Figure 1: Earth pressure increment due to differential settlement of embankment

Table 1: Guideline of earth pressure increment

h/B_0	**Coefficient of earth pressure increment, α**
$h/B_0<1$	1.0
$1\leq h/B_0<2$	1.2
$2\leq h/B_0<3$	1.35
$3\leq h/B_0<4$	1.5
$4\leq h/B_0$	1.6

h: depth of soil cover, B_0: width of a culvert

2. APPARATUS AND TEST PROCEDURE

2.1 Trapdoor apparatus

Overall structure of the trapdoor apparatus is shown in Figure 2. It consists of a soil chamber, movable base blocks, sensors and a supporting frame.

A soil chamber can accommodate model ground of 700mm wide, 294mm long and 555mm high. The base of the chamber consists of five separated movable blocks whose size is 99.8mm wide, 293.6mm long and 105mm high, and fixed parts in both sides, in order to create uneven settlement in the model ground, as schematically shown in Figure 3. Descent or ascent of the lower shaft controlled by a motor is transmitted to the upper shaft only when the upper clamp is tightened, so that any combination of base blocks can be chosen to move or stay.

Each base block is equipped with five two-way load cells to measure the load distribution on the base. A load cell is attached with a plate of 19.8×199.6mm. Its loading capacity is 0.3kN for both normal and shear forces.

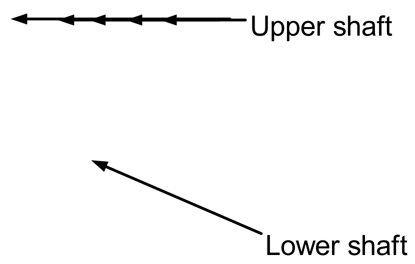


Figure 2: structure of the trapdoor apparatus

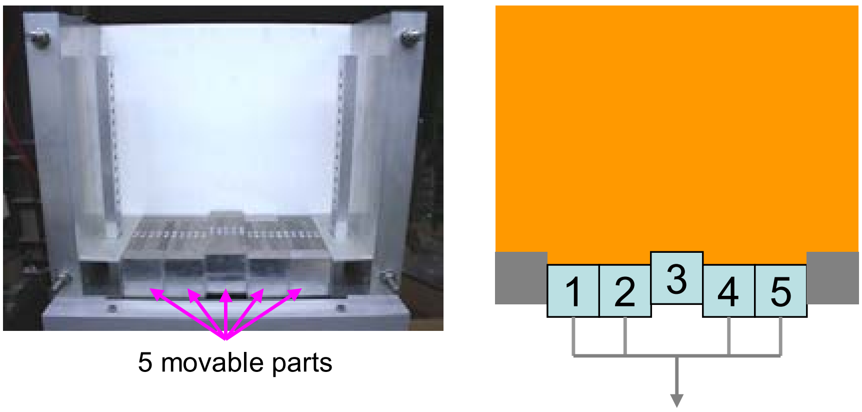


Figure 3: Reproducing an uneven settlement in the model ground

2.2 Model ground and test procedure

A model ground was prepared by the multiple sieving method, using dry Toyoura sand, uniform clean sand. The depth of soil cover, h, was varied to be 1B (B: width of a trapdoor), 2B, 3B, 4B and 4.5B. The relative density of the ground was 95% (ρ_d=1.58g/cm^3) and 40% (ρ_d=1.44g/cm^3). Therefore, 10 cases of model ground were tested in total. In all cases, four trapdoors in both sides (base block 1, 2, 4 and 5 in Figure 3) were descended at a rate of 0.012mm/min up to displacement δ=10mm, while the central trapdoor (base block 3) was unmoved.

3. REDISTRIBUTION OF STRESS IN THE GROUND

The earth pressure distribution on the base in test case H=4B, Dr=95% is presented in Figure 4. At the initial state (δ=0mm), normal as well as shear stress distribution was almost uniform within 1 to 5 trapdoors, although there seem to be scatter to some extent. The average of measured normal stresses was equivalent to the overburden pressure calculated from the depth of soil cover. Redistribution of stresses occurred as soon as descent of trapdoor started. Normal stress acting on central base block (3) significantly increased while normal stress on descending base blocks (1, 2, 4, 5) decreased. At δ=1.5mm, the average normal stress of base block (3) became maximum and it was stabilized at around δ=8mm. The distribution of normal stresses on the base 3 was concave shape. The stress at the sides was higher than that at the center, but the difference became smaller at the larger displacement. Shear stress distribution indicated that the there was some lateral symmetric displacement of the soil in the ground.

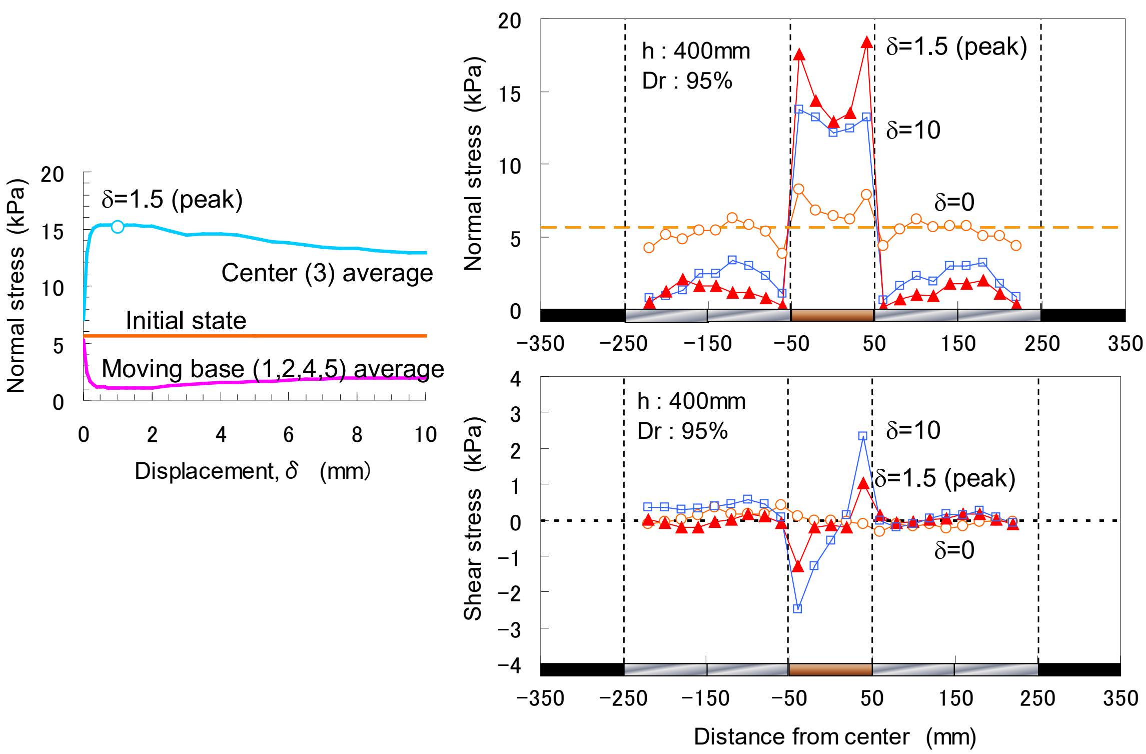


Figure 4: change of stresses on the base (h=4B, Dr=95%)

Deformation of the ground at δ=10mm is shown in Figure 5. Coloured sand was placed at the interval of 50mm to assist the observation of the ground deformation. Shear planes developed from the edges between unmoved and moving base blocks at an angle of 19˚ at early stage of test. In later stage, other shear plane developed at around 10˚. Those shear planes further developed until they formed arching above the moving base blocks.

In Figure 6, normal stress distributions for test cases of various h, ranging from 100 mm to 450 mm, are presented. It is clearly shown that the normal stress on the central base block was larger at larger h for both at peak and δ=10mm.

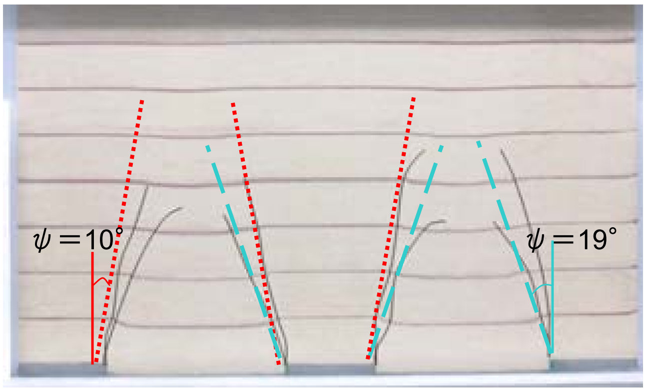


Figure 5: Deformation of mode ground (h=4B, Dr=95%)

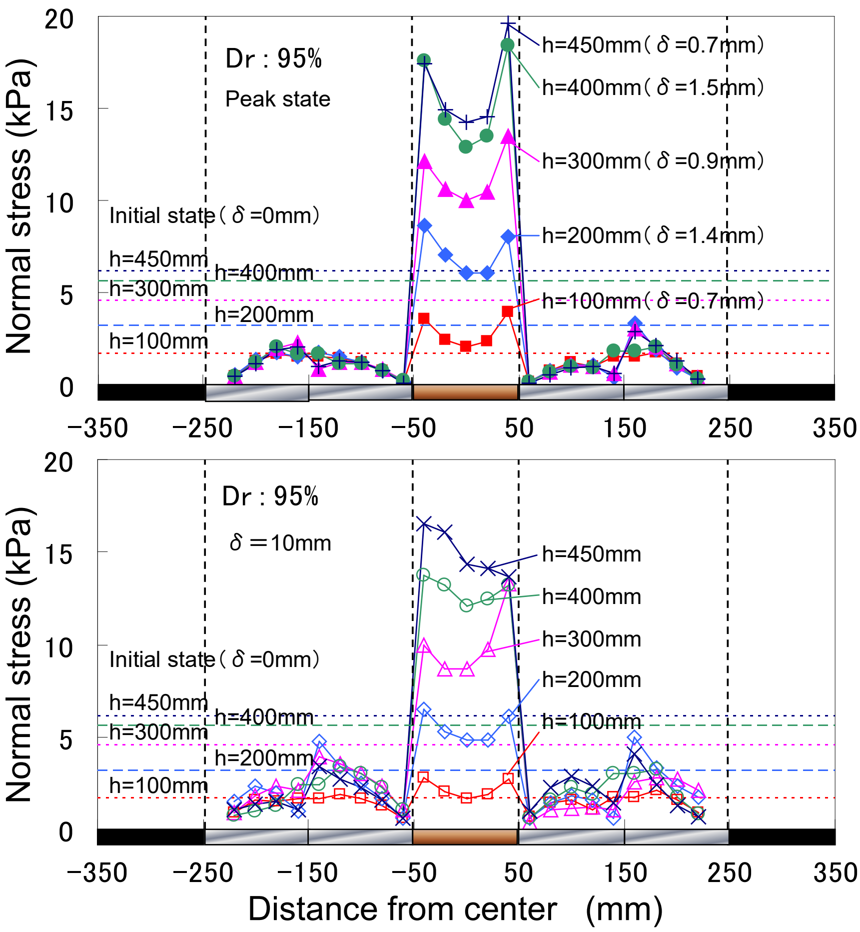


Figure 5: Relationship between h and normal stresses (h=4B, Dr=95%)

Earth pressure distribution for the cases of loose model ground (Dr=40%) is presented in Figures 6 and 7. Overall trend is similar to the case of dense ground, except that the stress redistribution developed gradually and there was no distinct peak state.

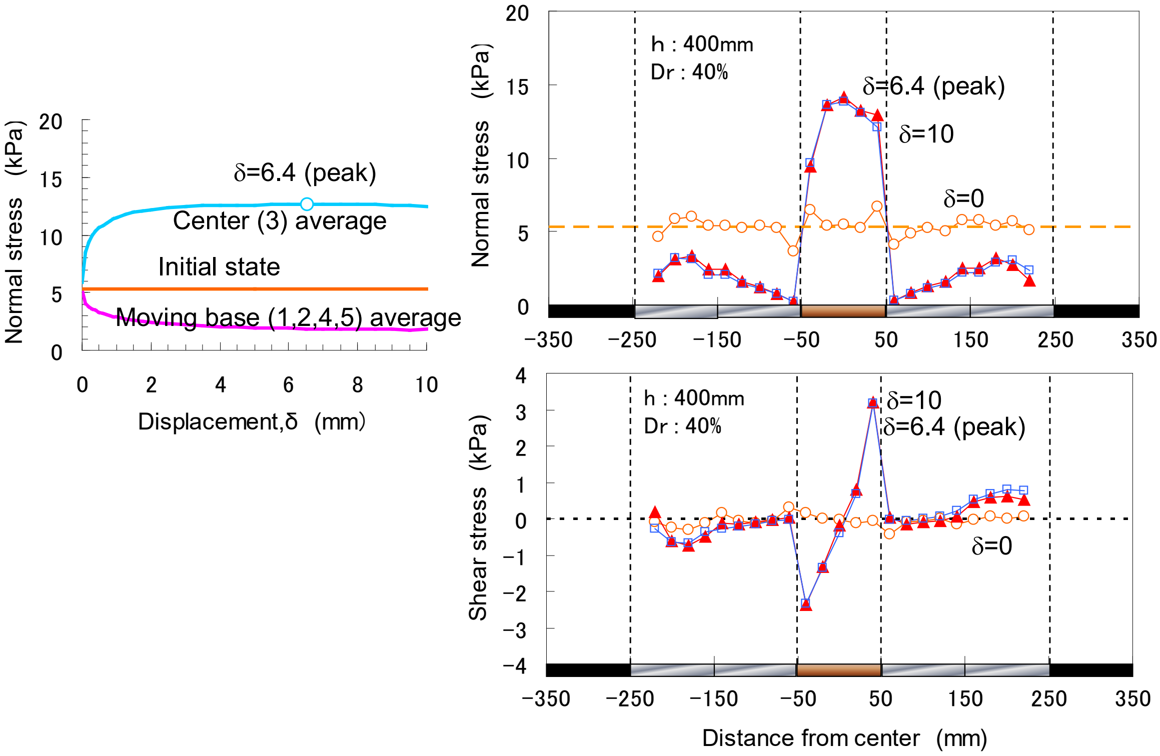


Figure 6: Change of stresses on the base (h=4B, Dr=40%)

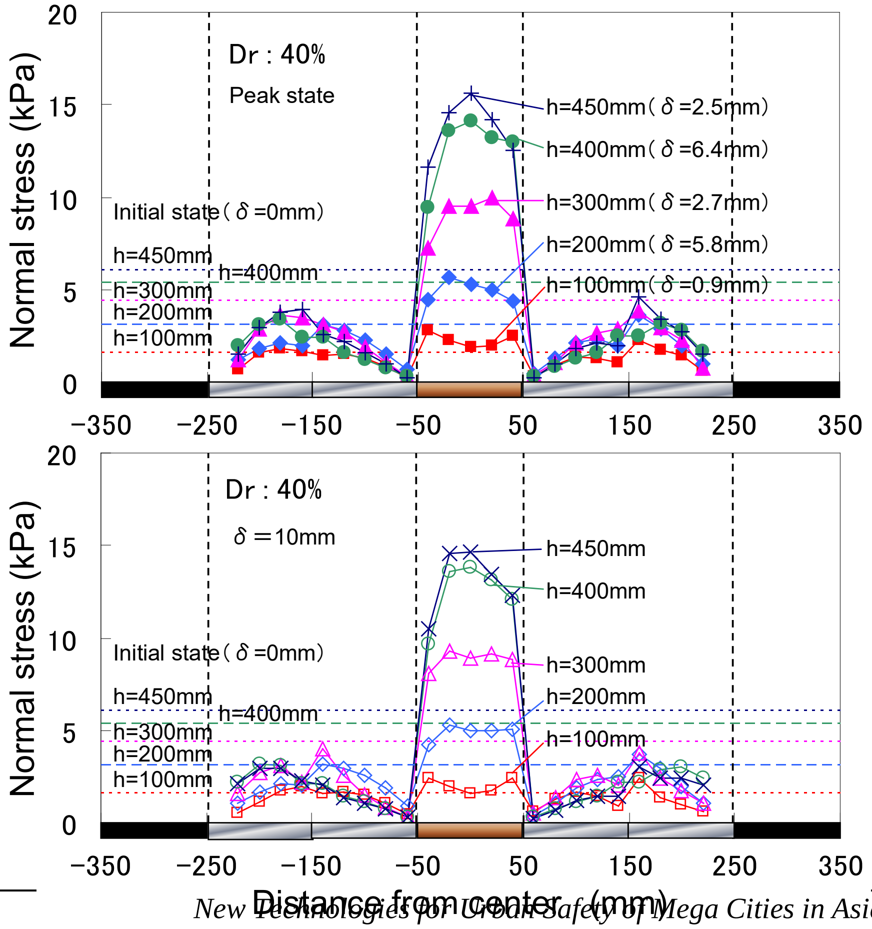
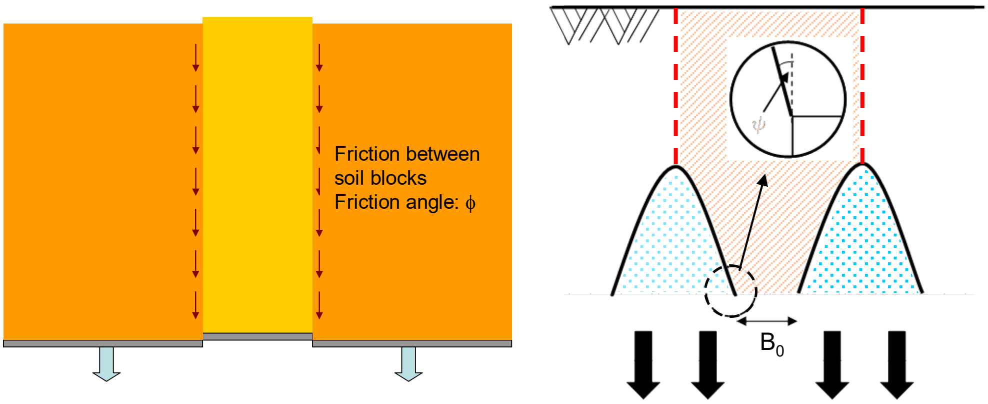


Figure 7: Relationship between h and normal stresses (h=4B, Dr=40%)

4. ESTIMATION OF EARTH PRESSURE INCREMENT

Earth pressure increment due to differential settlement can be estimated, assuming that the soil above the buried structure was pulled down by shear forces acting on the lateral surface of the soil block as shown in Figure 8a, applying Terzaghi's theory. In that calculation, it is not easy to appropriately determine the earth pressure coefficient, K (Kikumoto et al. 2005, Kuwano et al. 2007).

On the other hand, in this study, based on the pattern of ground deformation observed in trapdoor tests, overburden soil area for central and moving base blocks was assumed as shown in Figure 8b. It was found that when arching area was developed after the formation of shear plane, stress redistribution seemed to be stabilized. Stone & Muir Wood (1992) reported that the angle of shear plane developed in trapdoor tests agreed to the dilatacy angle of the soil. Therefore, it was considered that the moving base blocks carried only the soil within the ground arching. It was formed by shear planes initiated from both edges of moving base blocks. Physical and mechanical parameters used for the calculation is presented in Table 2.



a) following Terzaghi's theory

b) based on the observation of ground deformation in trapdoor tests

Figure 8: Assumption of overburden soil area

Table 2: Physical and mechanical parameters for the model ground

	Dry density, ρ_d	Relative density, Dr	Dilatancy angle, ψ
Loose state	1.44 g/cm^3	40 %	10°
Dense state	1.58 g/cm^3	95 %	19°

Values of earth pressure increment coefficient, α, were calculated by the simplified manner described above and compared with the measured values in trapdoor tests in Figure 9. The proposed simple calculation can give reasonable estimation of α for both loose and dense model ground. The difference of α at peak and residual state for dense ground can be explained when the angle of shear planes for each state is taken into account. It is implied that if the displacement reaches much larger and the dilatancy angle of soil becomes zero, it may approach to the assumption of Terzaghi's theory.

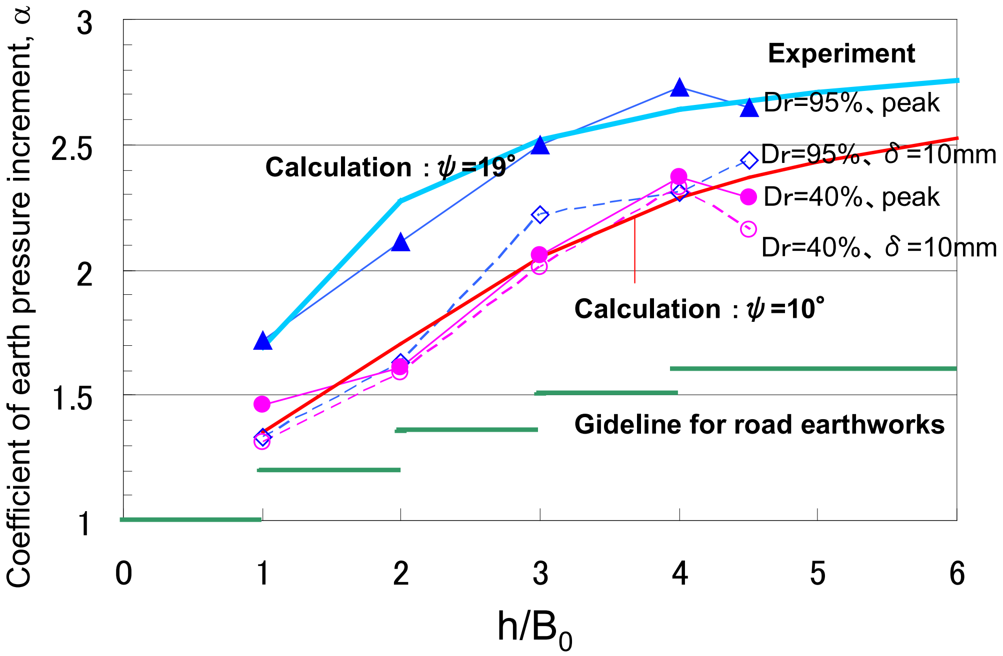


Figure 9: Comparison of coefficient α

5. CONCLUSIONS

In order to evaluate the increase in vertical earth pressures acting on a buried structure due to the differential settlements, a series of trap door tests was conducted. The following conclusions have been obtained;

- An increase in vertical earth pressures on a structure is affected by a depth of a buried structure, mechanical and physical properties of soil.
- Increments of vertical pressures obtained in series of experiment can be roughly simulated by the simple calculation, where the area of soil arching developed above the descending base blocks is taken into account.

REFERENCES

General guidelines for road earthworks - culvert work -, 1999. Japan road association, ISBN 978-4889504101, Maruzen Print Co. Ltd. (in Japanese).

Ebizuka,H. and Kuwano,R., 2009, Trap Door Tests for Evaluation of Stress Distribution around a Buried Structure, *Proc. 8th International symposium on new technologies for urban safety of mega cities in Asia*, USMCA, Inchon, October 2009, 245-250.

Kikumoto, M., Kishida, K., Kimura, M. and Tamura, T., 2005. Formula for calculating the distributions of vertical earth pressures around a tunnel, the 40th domestic conference of geotechnical engineering, *Proceedings of the 40th annual conference*, Japanese Geotechnical Society, Hakodate, July 2005, Paper No. 918. (in Japanese).

Kuwano, R., Horii, T. and Kohashi, H., 2007, Increment of Earth Pressure Acting on a Buried Box Structure due to Differential Settlements, *New Frontiers in Chinese and Japanese Geotechniques, Proceedings of the Third Sino-Japan Geotechnical Symposium,* 2007, 309-314.
Stone, K.J.L. & Muir Wood, D.,1992, Effects of Dilatancy and Particle Size Observed in Model Test on Sand, *Soils and Foundations*, Vol.32, No.4, 43-57.

Evaluation method of cover concrete air permeability considering water content

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ABSTRACT

Current verification of structural concrete quality is checked by printed records, compressive strength test at acceptance inspection, and so forth. However, in real structures quality of cover concrete should also consider durability. Consequently, a non-destructive inspection method such as on-site air permeability test (TORRENT) has been suggested as a durability evaluation method in recent years, but there is a possibility that this method cannot consider the influence of water content. This research aims to propose a quality control method that can evaluate the cover concrete quality of real structures. Specimens simulating structural members were cast and experimental results were compared to study the influence of different aspects such as dimensions and curing conditions on the non-destructive test results and, from this analysis, a method considering the influence of water content on quality evaluation was proposed. Future research is necessary to obtain more data for durability evaluation and to improvement the evaluation method.

Keywords: *water content, air permeability, non-destructive testing, durability, cover concrete*

1. INTRODUCTION

1.1 Background and Aims

Durability of structural concrete is highly influenced by the thickness and quality of cover concrete which protects steel bars from corrosion factors such as water, O_2, CO_2, chloride ion, and so on. However, although compressive strength test with test pieces cured in water is used as the acceptance inspection and Schmidt hammer is used as inspection for estimation strength of actual construction, these are just used as substitute indices to evaluate durability. This means that it is necessary to establish a complete inspection method which can evaluate the durability of cover concrete directly.

In recent years, inspection utilizing air permeability test (Torrent method) has been performed but it was found that water content has an influence on air permeability. Therefore, it is necessary to consider water content in this method, so this research aims to propose a complete inspection method using test pieces and examines this method experimentally.

1.2 Conceptual method

To develop this method considering water content it is necessary to understand the influence of water content on quality of concrete cover by using non-destructive inspection. A conceptual diagram of the inspection method suggested in this study is shown in Figure 1. First, the coefficient of air permeability of standard cured test pieces (KT-D) is measured at time of mix design. KT-D is compared with test pieces gathered from the actual ready mix concrete which met acceptance inspection and were cured in standard water conditions (KT-R1) in order to confirm the quality of the ready mixed concrete. At the same time, test pieces are cured and exposed in the same conditions as the actual structure (KT-R2). KT-R2 is compared with the coefficient of air permeability of actual structure (KT-S) to confirm the difference between test pieces and actual structure considering the influence of the water content. Therefore, the influence of measuring point and construction ("α") and the effect of dimensions on drying speed ("β") were examined experimentally.

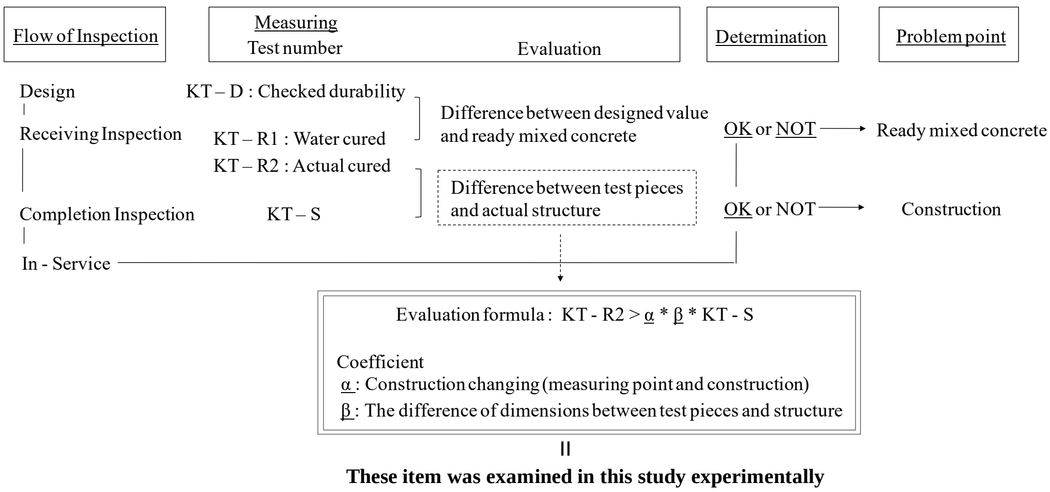


Figure 1: Conceptual diagram

2. EXPERIMENTAL OUTLINE

2.1 Sample specifications

Specimens for simulating structural members (column and wall) and test pieces for comparative examination were cast with concrete mix proportions given in Table 1 and dimensional data and method of casting shown in Figure 2. The surface of structural member specimens were sealed without using aluminum tape to stop movement of water except through two faces. This was done to simulate the sections of larger members. Test pieces for understanding the influence of thickness and the number of drying faces were also sealed with aluminum tape. The length of one side of the test pieces was set to double the actual length "L".

Table 1: Concrete mix proportions

W/C (%)	s/a (%)	Amount of unit (kg/m^3)					Slump (cm)	Air (%)
		W	C	S	G	AE		
52.7	45.8	175	333	806	974	2.97	13.5	6.0

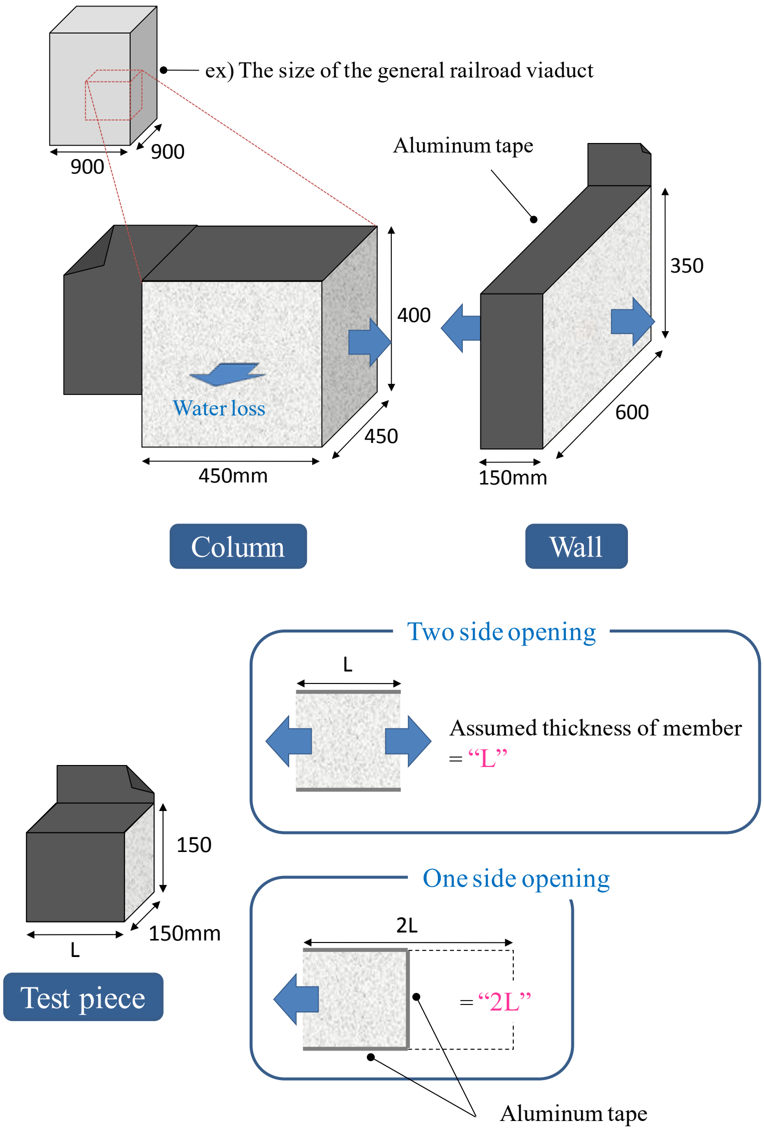


Figure 2: Dimensional data

Experimental factors are shown in Table 2. Assumed thickness of members were prepared for standards from 100 mm to 900 mm by changing length and the number of open faces. The period of sealed curing was 5 days. After sealed curing, specimens were cured under constant temperature and humidity (20℃, R.H.60%).

Table 2: Sample conditions

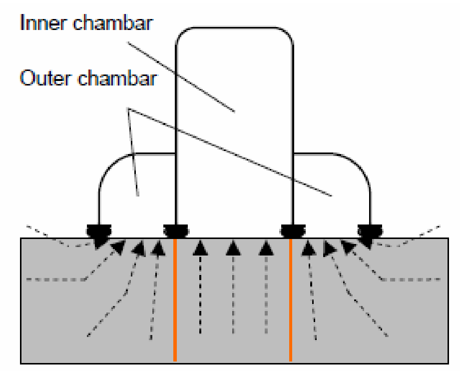
Sample type	Thickness (mm)	Number of open faced	Assumed thickness of member
C (Column)	450	1	900
W (Wall)	150	2	150
P-100	50	1	100
P-150	150	1	300
P-300	150	2	150
P-530	530	2	530
P-900	450	1	900

2.2 Measurement method

The main measurement item is air permeability and water content. The Torrent method is a means for measuring air permeability which can be used in the field (Torrent, 1992). This method uses a two chamber cell, with an inner and outer chamber, based on the guard-ring principle (Figure 3). The coefficient of air permeability by Torrent method (KT) is computed by following the numerical formula given in Equation 1. As a result of the investigations undertaken with this device, a classification of the quality of the "covercrete" can be given as presented in Figure 4, based on the values of KT measured on relatively young concretes, which are relatively dry. For example, Grade A corresponds to well-cured and compacted high strength concrete; at the other extreme, Grade E corresponds to low strength concrete which is not subjected to any moist curing. In this research, air permeability was transformed using base-10 logarithm (Log (KT)).

$$KT = \left(\frac{Vc}{A}\right)^2 \frac{\mu}{2\in Pa}\left[\frac{ln(Pa+\Delta P\tau/Pa-\Delta P\tau)}{\sqrt{t}-\sqrt{t_0}}\right]^2 \quad (1)$$

KT : Coefficient of air permeability (m^2)
Vc : Volume of inner cell system (mm^3)
A : Cross sectional area of inner cell (mm^2)
μ : Viscosity of air (Ns/m^2) ($2.0*10^{-5}$)
$\in$: Estimated porosity of the cover concrete (m^3/m^3)
Pa : Atomospheric pressure (N/m^2)
ΔP : Times (s) at the end of the test (N/m^{-2})
T : Times (s) at the end of the test
T0 : Times (s) at the beginning of the test (=60s)



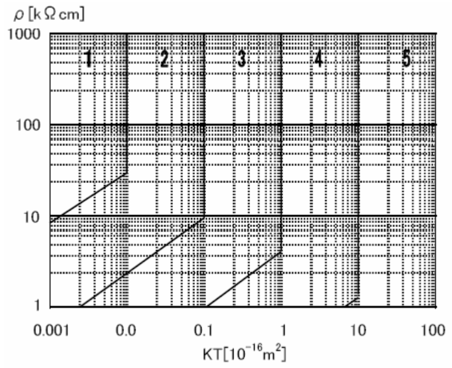


Figure 3: Schematic of Torrent

Figure 4: Evaluation chart

Water content was measured using an electrical resistance concrete/mortar moisture tester HI-800 (Figure 5). Compared to other methods for measuring water content used in Japan, this method is simple and measurement of the water content in the depth direction is possible.

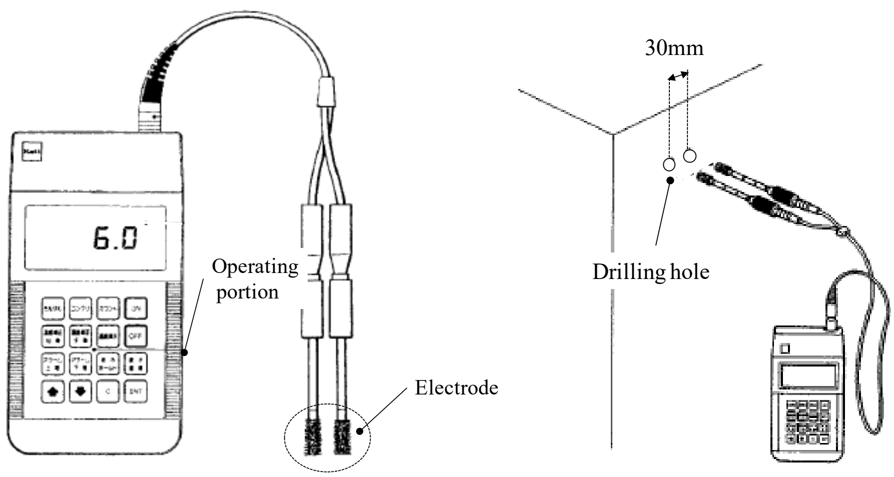


Figure 5: Schematic of HI-800

3. RESULTS AND DISCUSSION

3.1 Air permeability test

The results of test pieces by assumed thickness are shown in Figure 6. The standard deviation is also shown for the results of P-100 and P-900. The air permeability of P-900 was lower and P-100 slightly higher compared to the other conditions. However, the influence of thickness on air permeability in this experiment was small because the range of the standard variations was bigger than the difference of the assumed thickness. Regardless of conditions, air permeability increased with increase of material age. It was very likely that the cause is influence of drying, but air permeability is affected by both water content and development of pore structure, so both factors need to be considered.

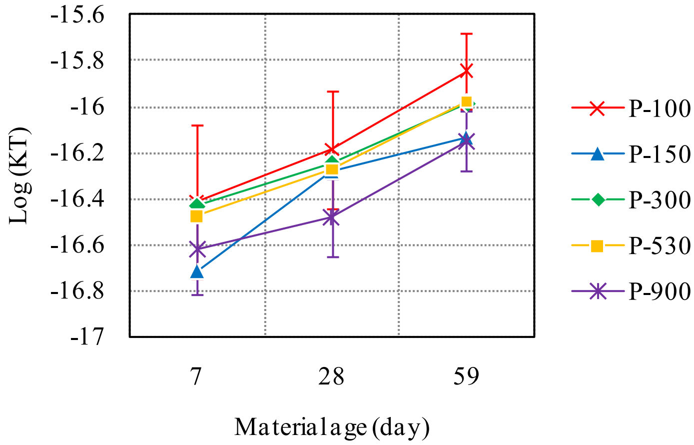


Figure 6: Relationship between air permeability and material age

To understand the influence of height on air permeability, the relationship between height of simulated structural members and Log (KT) is shown in Figure 7. The results showed that air permeability increased with increase in height. In the upper part, air permeability increases greatly with the progress of the materials age, but in the lower part there was little change due to age. This may mean that difference in quality influences drying speed. The result of the wall is constant regardless of height, which confirmed that quality was about the same.

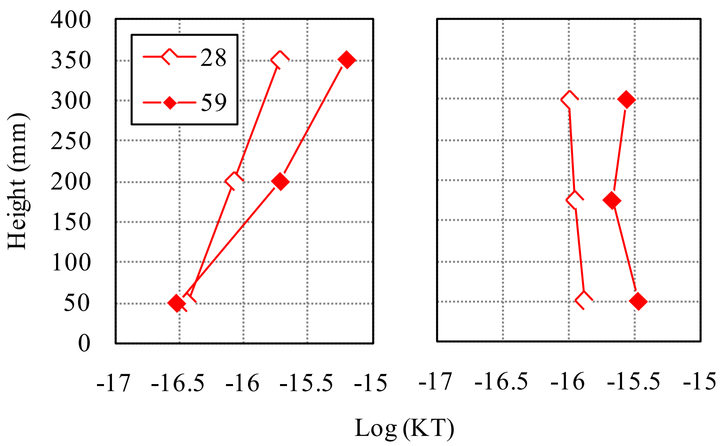


Figure 7: Relationship between height and air permeability
for column (left) and wall (right)

From the relationship between Log(KT) and material age some approximation curves were calculated, where the slope of the curves was defined as the increase speed of air permeability. These results are shown in Figure 8. The increase speed of the test piece is slightly smaller in comparison with both structural members. This means that the quality of P-300 was better than both members because the test piece is not influenced by construction. In addition, the influence of height is smaller for the wall than for the column. The wall has a smaller cross section than the column, so the influence of material segregation may have been small.

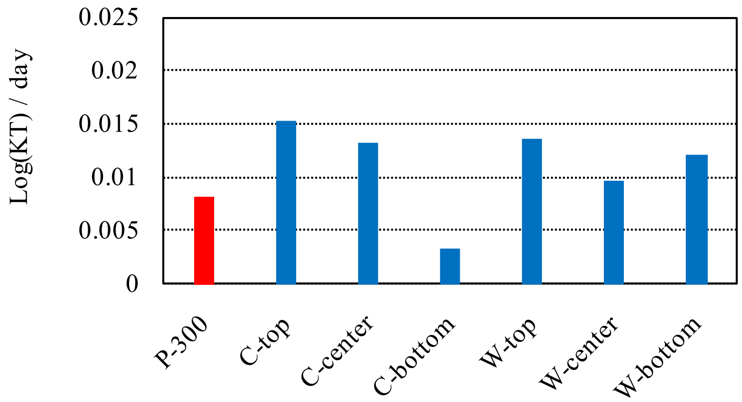


Figure 8: Rate of increase of air permeability (all material age)

Next, the rates of change of air permeability over two time periods, 7 to 28 days and 28 to 56 days, are shown in Figure 9. After 28 days, the rate of change decreased and the difference in speed by thickness also decreased. As for this reason, drying speed was different by quality of early age concrete. But, the influence of quality on drying speed was decreased with material age increased after the 28th day, and it may become constant regardless of quality in future. Therefore, when the drying speed of test pieces and members are same, it is necessary to be examined whether air permeability evaluates quality expressing true pore structure.

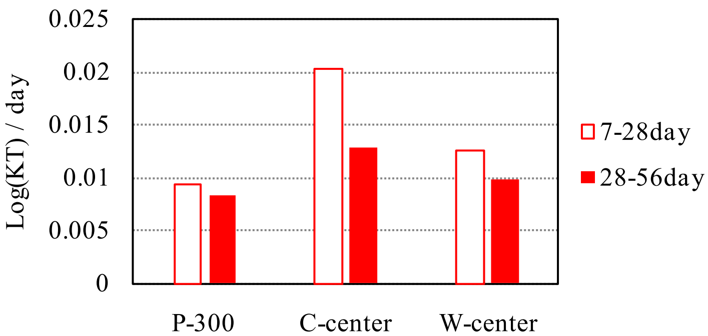


Figure 9: Air permeability rate of change over time

3.2 Water content measurement results

Water content results as measured from the surface of test pieces are shown in Figure 10. P-100 was small relative to the other test pieces, but the other test pieces were generally similar regardless of thickness, with roughly a 3% difference in water content ratio between the surface and at a 70 mm depth. 56 days results were roughly 1% to 2% less than 28 day results, regardless of depth and specimen thickness.

Next, the water content measurement results for test pieces and members are shown in Figure 11. The test piece results are slightly lower but at roughly the same level as the member results, which are similar for both walls and columns. Similar to the test piece results shown above from 28 to 56 days the water content ratio decreased about 1% to 2% regardless of depth from surface. Therefore, it might be said that drying influenced the increase in air permeability. However, the electrical resistance may decrease with changing pore structure, which is dependent on the progress of the hydration reaction, so it is also necessary to examine the influence of pore structure on water content ratio.

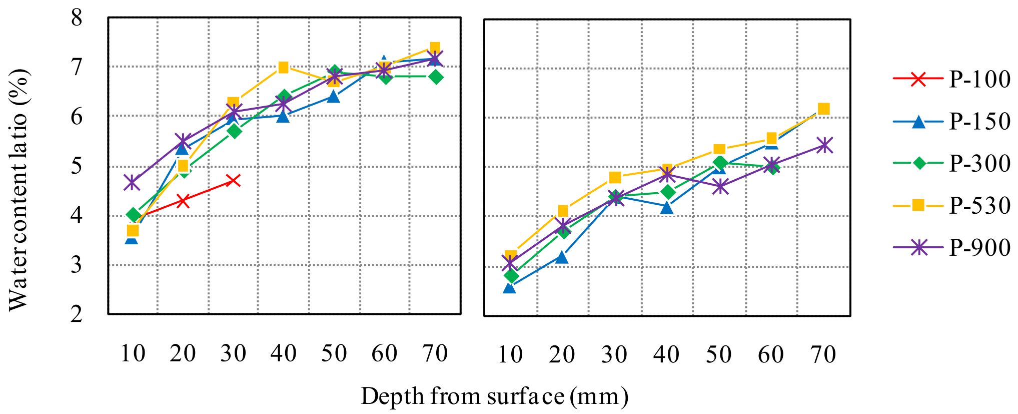


Figure 10: Water content results in test pieces by thickness
(left: 28 days, right: 56 days)

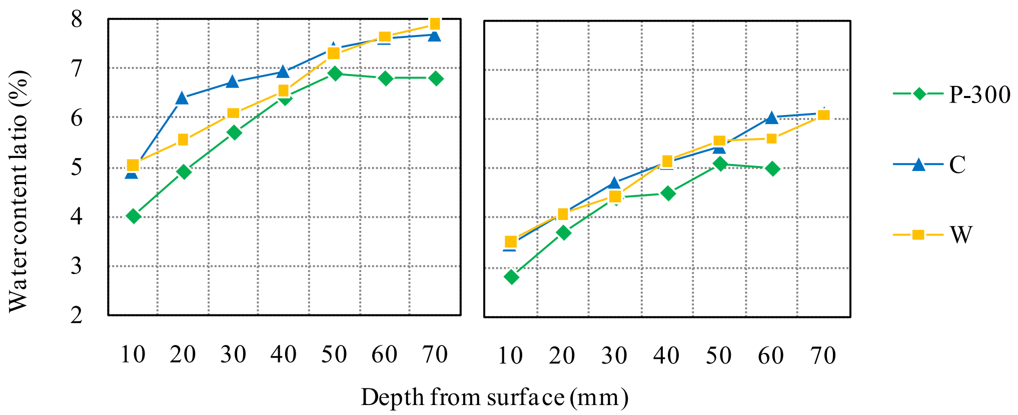


Figure 11: Water content results in test pieces and members
(left: 28 days, right: 56 days)

4. CONCLUSIONS

This study proposed a quality evaluation technique for on-site cover concrete using the air permeability test. The conclusions of this study are as follows.

1) To reduce the influence of water content on the air permeability of cover concrete, the curing and exposure method for test pieces should be the same conditions as the actual structure.
2) Air permeability at the surface increases as the materials age. This tendency differs depending on the type of member and height. It may be attributed to the difference in drying speed, which in turn is caused by difference in quality.
3) The thickness has little influence on water content, which decreased over time. Therefore, it is possible that drying influenced the increase in air permeability.

In the future, when the drying speed of test pieces and members are same, it is necessary to be examined whether air permeability evaluates quality expressing true pore structure.

ACKNOWLEDGEMENT

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REFERENCES

Torrent, R.J., 1992. *A two-chamber vacuum cell for measuring the coefficient permeability to air of the concrete cover on site*, Material and Structures, Vol.25, pp.358-365.

A Research on Business Continuity Management of Big Private Companies in Japan
—A case of the new influenza pandemic in 2009

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ABSTRACT

A pandemic flu is one of the biggest risks for companies that are involved in Business Continuity Plans. However, few studies explain risk management techniques for a pandemic flu. In this study, we administered a questionnaire survey mainly to the First Section listed companies listed in the TSE to assess the status of the formulation of a Business Continuity Plan (BCP) for a pandemic flu from 2008 to 2010 and to clarify the countermeasures for the pandemic flu in 2009. As a result, we observed that a major portion of the companies made BCPs and took advanced measures to counter a pandemic flu.

Key Words: Business Continuity Plan (BCP), Large Companies, New Influenza Pandemic, Questionnaire Survey

1. INTRODUCTION

The sense of crisis as a result of various risks such as natural disasters and infectious diseases has risen in enterprises, and the number of companies that have made Business Continuity Plans (BCP) or other kinds of plans or manuals for disaster prevention has increased in recent years. After the new H1N1 influenza pandemic in May 2009, new influenza has become one of the biggest risks that encourage companies to make Business Continuity Plans.

Few studies explain the risk management systems in enterprises, especially as far as an influenza epidemic or pandemic is concerned. An exception can be made in the case of Sashida (2008), who indicated the basic concepts and conditions for damage prediction and countermeasures for the new influenza pandemic, and Beniya (2009), who clarified the current status of BCPs of companies for various hazards including a new influenza pandemic. Despite this, it is important for companies to be aware of how to respond against such a pandemic.

The aim of this study was to identify the problems in, and to learn lessons from a case of the new H1N1 influenza pandemic in 2009. We also aimed to clarify the status of crisis management in large companies in Japan by comparing the situations before and after the pandemic in 2009.

2. METHOD

We conducted a questionnaire survey of the First Section listed companies in the Tokyo Stock Exchange (TSE) in 2008 and 2010 to clarify the situations of the formulation of BCP for a pandemic influenza or natural disaster and to clarify the countermeasures taken by the companies for the H1N1 pandemic in 2009.

Table.1 Outline of questionnaire survey for large enterprises

Object	Five hundred and eighty-seven large companies that were listed in the first section of the TSE were chosen according to the ratio of industry specification
Content of questions	1) Planning situation of BCP or disaster prevention plan/manual 2) Kind of assumed crisis in the plan/manual 3) Progress situation of measures against natural disasters or new influenza 4) Correspondence to the new influenza pandemic in 2009, etc.
Execution method	Mailing distribution and mailing collection
Execution time	1) The first investigation "the 2008 survey" in November and December 2008 (about half a year before the new influenza pandemic in 2009) The collection rate was 26.6% (156 companies) 2) The second investigation "the 2010 survey" in March and April 2010 (about one year after the new influenza pandemic in 2009) The collection rate was 27.9% (164 companies)

2. PLANNING STATUS FOR A NEW INFLUENZA PANDEMIC

Figure 1 shows the planning status of the BCP or disaster prevention plan in 2008 and 2010. Most companies have recognized the importance of BCPs. The ratio of enterprises with BCPs increased from 41.7% in 2008 to 54.3% in 2010. Around 36.5% of the companies have a plan to make BCPs in addition to their existing disaster prevention plans.

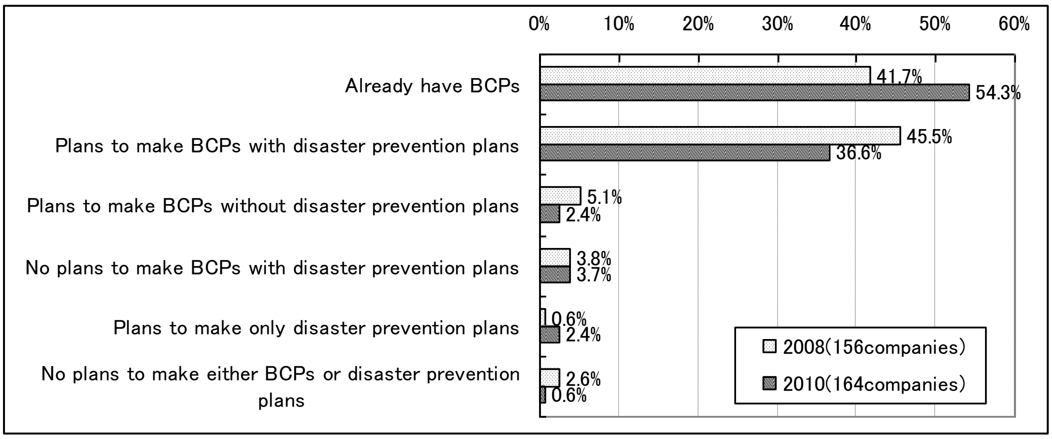

Fig.1 Planning status of BCPs or disaster prevention plans (Single Answer (S.A.))

Figure 2 shows the risk factors assumed in BCP. In the 2008 survey, the largest risk assumed by the companies that had or were making BCPs was that of earthquakes such as the "Tokyo Earthquake" (81.9%) and the "Tokai, Tou-Nankai, and Nankai Earthquakes" (70.1%). On the contrary, in the 2010 survey, the largest risk was that of a "pandemic of an infectious disease like new influenza." The percentage of companies that indicated that “the largest risk is a pandemic of an infectious disease like new influenza” was 86.9% in 2010, a 19.2 point increase from 2008. It is believed that the number of enterprises that settled on BCP assumed the new influenza as a risk that had been increased by the new influenza pandemic since May 2009.

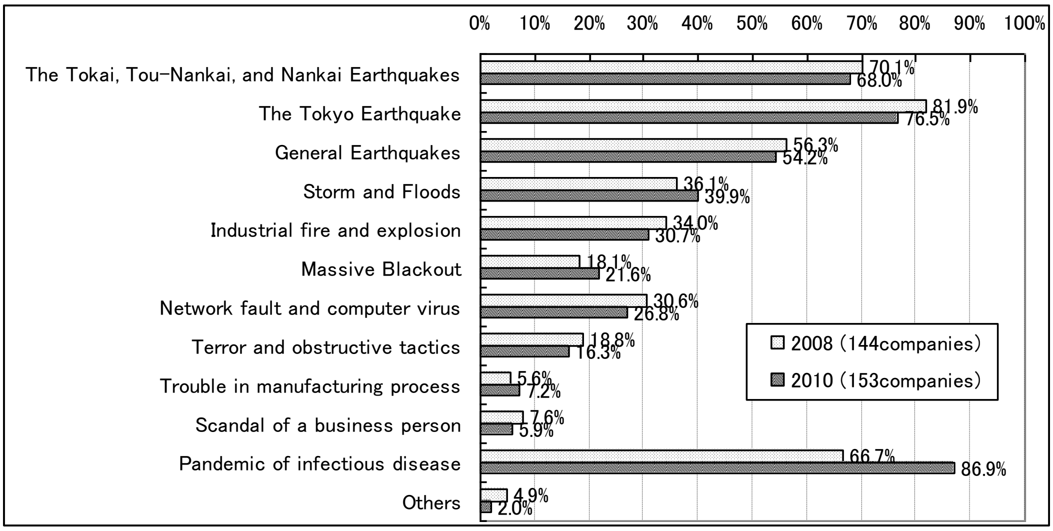

Fig.2 Risk factors assumed in BCP
(Multi Answer (M.A.), companies that have or plan to make BCPs)

3. CONUNTERMEASURES FOR THE NEW PANDEMIC FLU IN 2009

3.1 Planning

Figure 3 shows the situation of the plans at the beginning of the pandemic in 2009. When the new H1N1 influenza pandemic occurred in May 2009, more than half the enterprises had BCPs or similar plans that would enable them to deal with the new influenza. Around 53.0% of the enterprises had plans for new influenza with strong toxicity, such as the H5N1, while only 2.4% were prepared with a plan for a pandemic of a disease with weak toxicity, such as the H1N1.

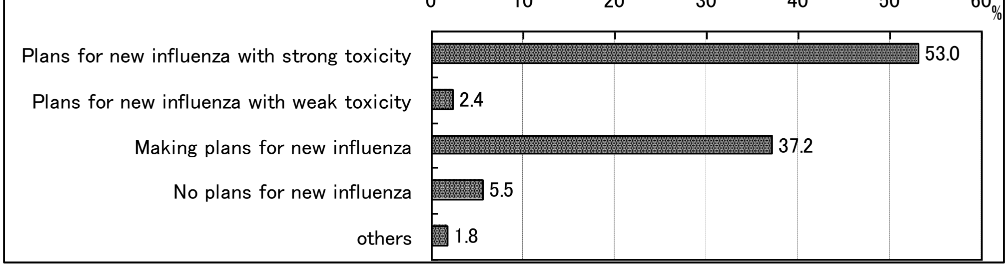

Fig. 3 Status of the plans for new influenza in May 2009
(S.A., 164 companies)

Figure 4 shows the application of the plans for the new influenza pandemic in May 2009. Against the pandemic of the new influenza with weak toxicity in 2009, 71.3% of the companies that had made plans for only those diseases with strong toxicity applied “a part of the plan for strong toxicity influenza,” and 10.3% of these companies completely applied "all of the plans for strong toxicity influenza."

Around 71.4% of the companies that did not have plans for the new influenza pandemic started to make these plans immediately after the pandemic of 2009, and 21.4% of the companies applied their existing disaster prevention plans or risk-management plans as substitutes that did not cover the new influenza pandemic.

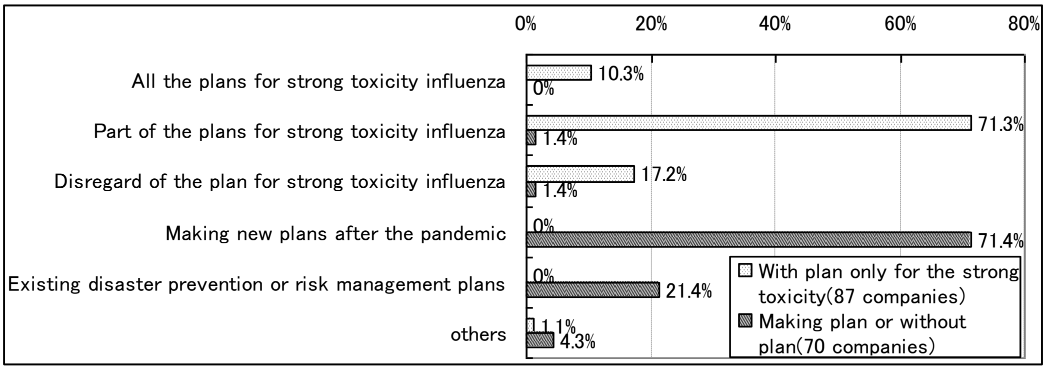

Fig. 4 Application of plans for the new influenza pandemic in May 2009 (S.A.)

3.2 Problems and Influences

Figure 5 shows the problems of the pandemic. The major problems indicated by the companies are "insufficiency of information about the infection and toxicity" and "difficulty in obtaining the mask or antiviral drug."

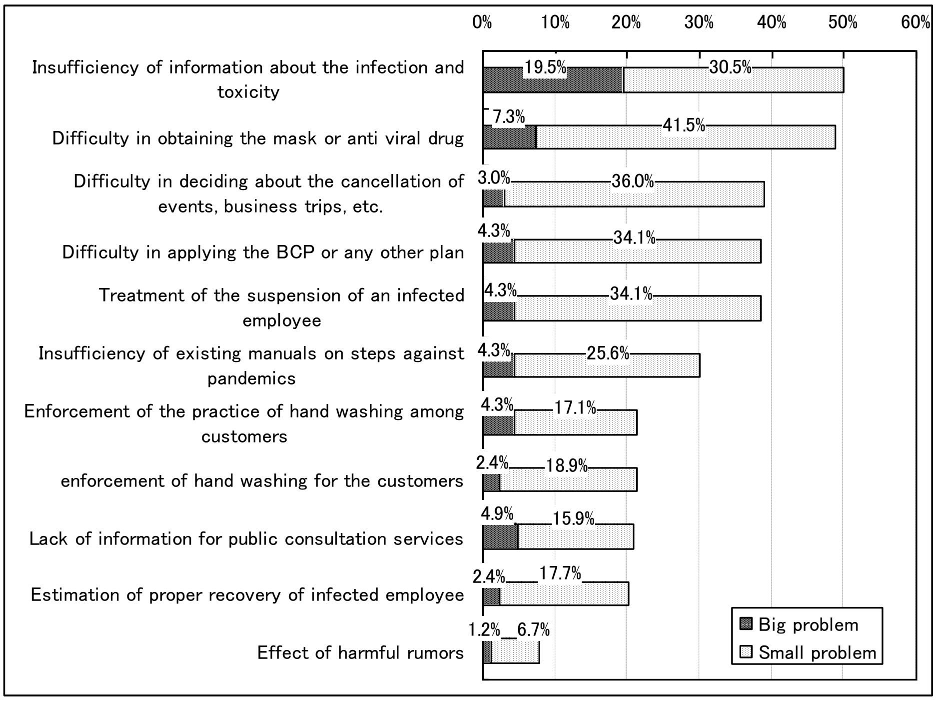

Fig. 5 Problems of the pandemic influenza in 2009
(S.A., 164 companies)

Figure 6 shows the effects of the pandemic on business.

The positive effects of the 2009 pandemic were seen in 63.4% of the companies, which indicated an "increase in crisis consciousness among employees," and in 62.2%, which indicated that the "pandemic is a chance to consider risk management or BCPs."

Negative effects of the pandemic were seen in 43.3% of the companies, which indicated that "the working system was affected because some of the employees or their family members had caught the disease." Moreover, 51.8% of companies indicated that "employees and their families were inconvenienced by the suspension of social facilities such as schools." This suggests that the closing of public facilities such as schools has a significant impact on the employee more than the direct effect of the infection on the employee or his/her family.

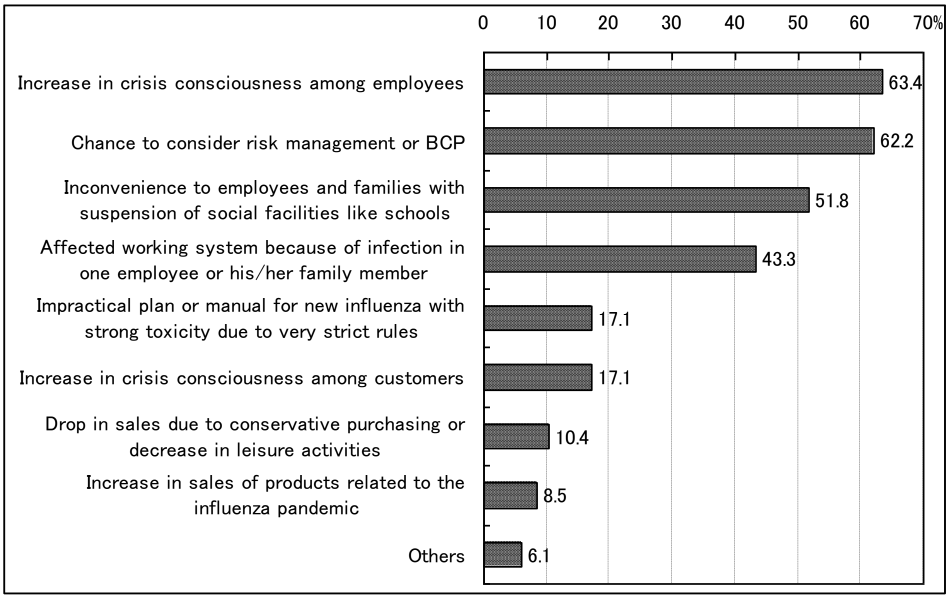

Fig.6 Effects of the pandemic on business (M.A., 164 companies)

Figure 7 shows the effects on sales according to the industry sectors. Further, with regard to the influence on sales, there is a 10.4% decrease due to conservative purchases and 8.5% increase in products related to the influenza. The sales of manufacturing companies tended to increase, while that of non-manufacturing companies tended to decrease.

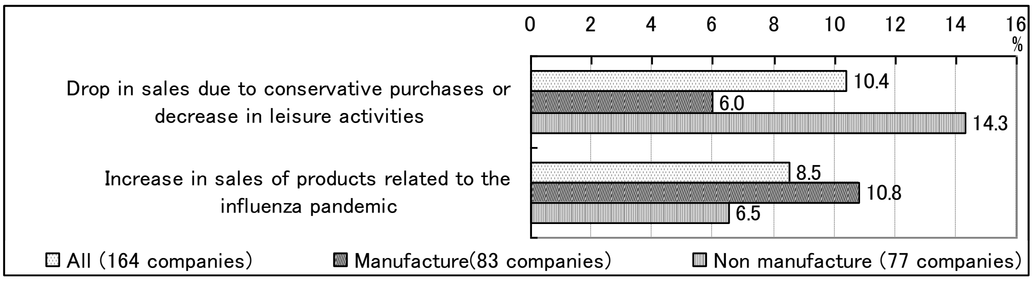

Fig.7 Effects on sales due to the new influenza pandemic according to the industry sectors (S.A.)

4. FUTURE COUNTERMEASURES FOR A NEW PANDEMIC WITH STRONG TOXICITY

Figure 8 shows the progress of countermeasures against the pandemic of a new influenza with strong toxicity. The ratios of “already in operation” increased largely from 2008 to 2010 in every countermeasure for the new influenza pandemic. Progress was seen in measures taken toward infection prevention, such as “stockpile of mask and disinfectant spray,” “infection prevention training for employees and their families,” and “forced stay-home program for infected employees.”

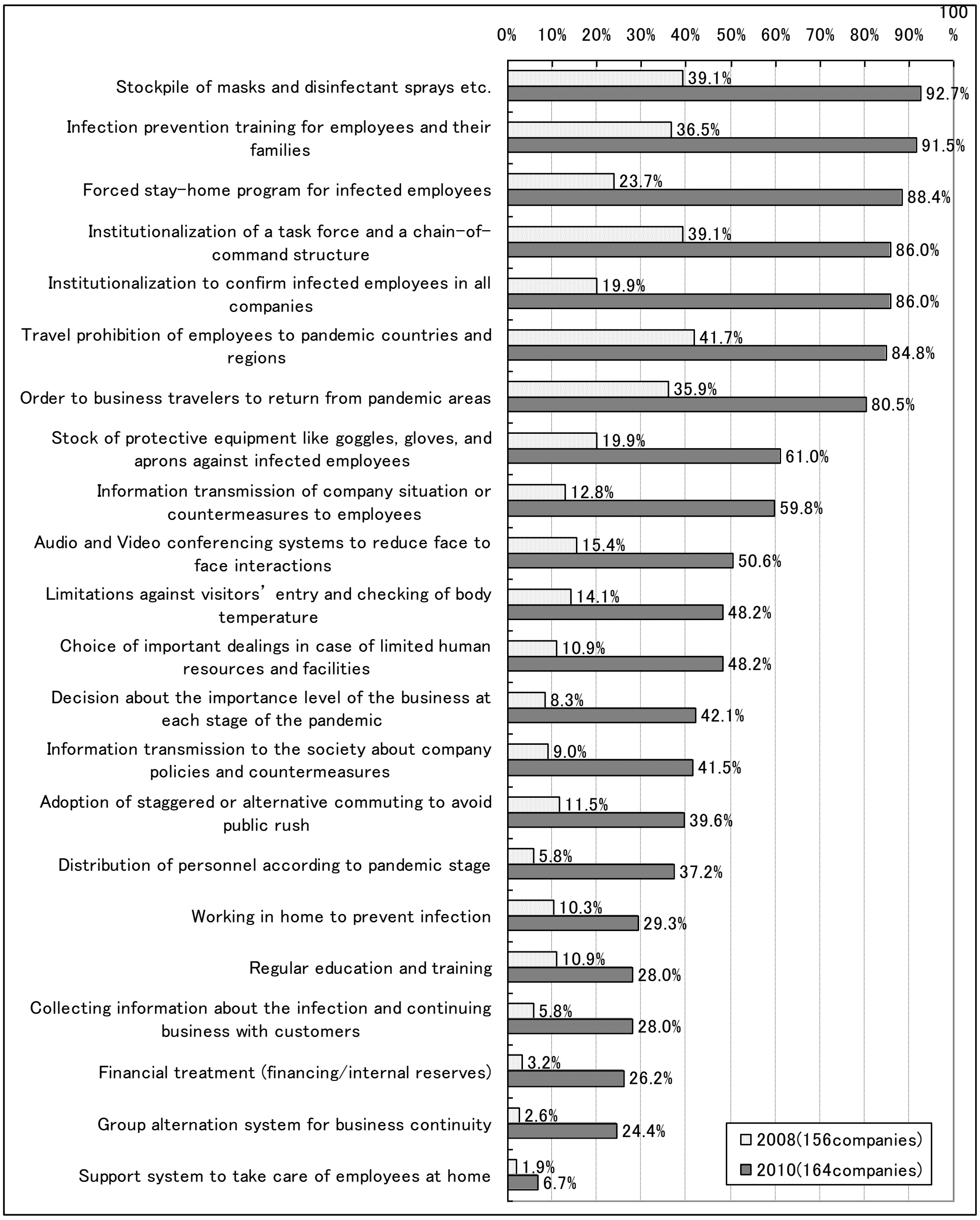

Fig. 8 Progress in countermeasures against the pandemic of new influenza with strong toxicity (The ratios of “already in operation”)

Figure 9 shows the current problems of countermeasures against a pandemic of new influenza with strong toxicity. The 2010 survey helped identify predictable problems of new influenza with strong toxicity, such as “countermeasures of the supply chain are insufficient” (51.8%), “the response plan, action plan, or BCP are not arranged well” (43.9%), and “the prospect of vaccination of the pre-pandemic vaccine is uncertain” (40.9%).

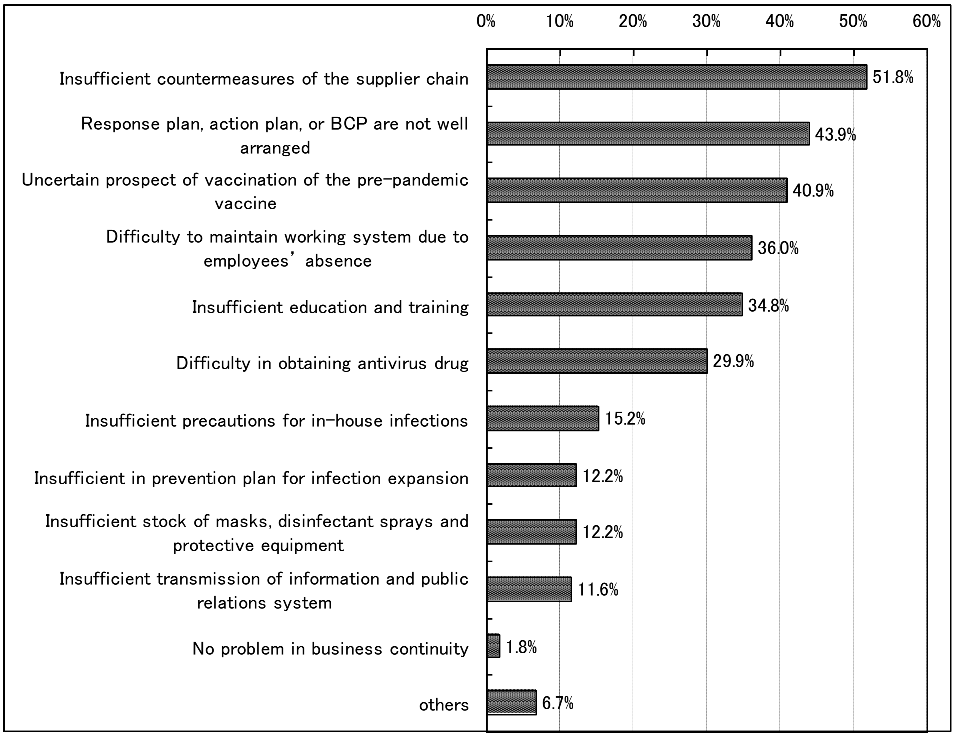

Fig.9 Problems of countermeasures against a new influenza pandemic with strong toxicity in March 2010 (M.A., 164 companies)

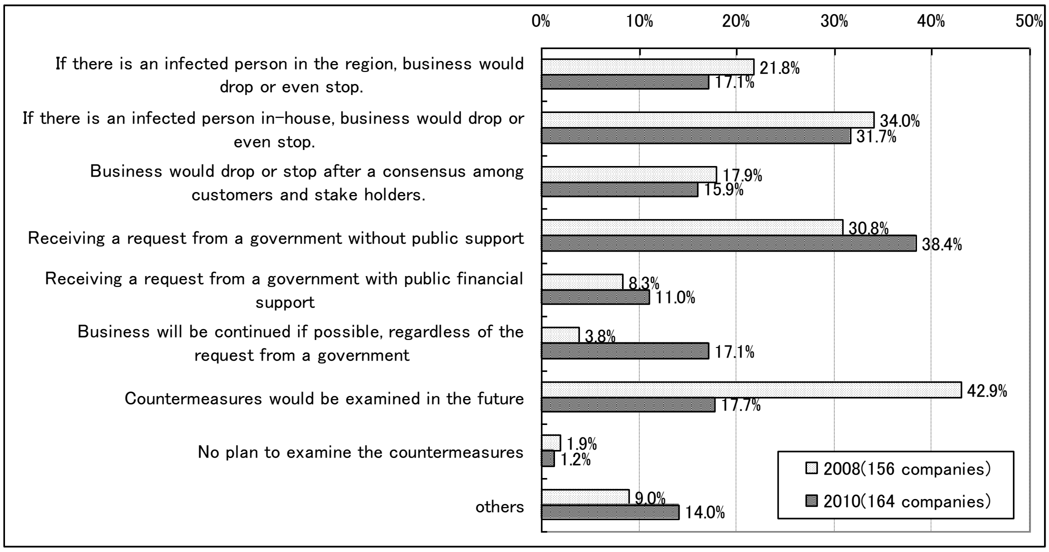

Fig.10 Conditions for downsizing or suspending the socially noncritical business place (M.A.)

Figure 10 shows the conditions for downsizing or suspending the socially noncritical business place. According to the central governmental guidelines, the socially noncritical business place would be downsized or suspended in the case of a pandemic. In the 2008 survey, the most common answer was “countermeasures will be examined in the future” (42.9%). However, it decreased to 17.7% in the 2010 survey, where the most common answer was “receiving a request from the government” (38.4%). On the other hand, 17.1% of the companies believed that “If possible, business will continue, regardless of the government’s request” in the 2010 survey.

5. CONCLUSION

5.1 Results

In this study, we administered a questionnaire survey to the TSE First Section listed companies in 2008 and 2010 to compare the situation before and after the pandemic of new influenza with weak toxicity in 2009. The main results are as follows.

1) Attitudes toward the Business Continuity Management in large companies were clarified. There were some differences between the attitudes in 2008 and 2010. Given the H1N1 pandemic in 2009, the number of companies with BCPs against new influenza increased. However, some problems remained, such as “risk management in the supply chain,” “countermeasures for the visitor,” “treatment of suspension from office and furlough,” and “support to the employee who recuperates at home.”
2) The situations and problems of the companies during the weakly pathogenic H1N1 pandemic in 2009 were clarified. The biggest problem indicated by many companies was the lack of information on the infection and toxicity. Employees needed to take care of their families because schools, nursery centers, welfare facilities, and so on were closed. This gave the companies an opportunity to enhance the employee's consciousness of crisis, and to improve the company’s crisis management.
3) The situations and problems of the measures were clarified for strong toxicity new influenza in 2010. The problem was the lack of BCP and BCM for the supply chains in all. Even if the influenza epidemic occurred, more companies intended to continue their noncritical business. Compulsory requests of the government for downsizing or suspension will be required to delay the influenza pandemic.

5.2 Consideration

The new influenza virus is not an already special risk. It became a risk that was generally assumed in the BCP of big enterprises after the new influenza pandemic with weak toxicity occurred in 2009. In the near future, the small and medium-sized enterprises will be requested to make BCPs, irrespective of whether they are big enterprises or government establishments.

There is a possibility that an optimized solution subject to the individual BCP of such an enterprise and public facility will become a cause of social disorder. If schools, welfare institutions, or socially important businesses are suspended, many employees would find it difficult to work. The larger the number of enterprises that tend to continue socially noncritical businesses in the case of new influenza pandemics, larger is the risk of infection.

The present actions taken to address the new influenza pandemic are defective. Governments can not deal with the pandemic adequately as leaders because they do not have sufficient authorities to control the social function. It is necessary to share a grand design as a kind of "Social Continuity Plan" to maintain important functions of the whole society and to establish laws like the Disaster Countermeasure Basic Act that can integrate the countermeasures of varied stakeholders.

REFERENCES

Tomohisa SASHIDA, The Pandemic Influenza : Public Sector Crisis Management and Regional Safety, *Proceedings of the Annual Conference of the Institute of Social Safety Science*, No.23, 2008

Shohei BENIYA, Keisuke KUBOTA and Hiroaki MARUYA, A Research on the Business Continuity Plans of Big Private Companies for a Pandemic Flu or Natural Disasters, *Proceedings of the Annual Conference of the Institute of Social Safety Science*, No.25, 2009

Collapse Analysis of RC Structures using Improved Applied Element Method

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ABSTRACT

In this paper, the Improved Applied Element Method (IAEM), which was originally developed as an effective analysis technique of large-scale steel structures up to complete failure under different hazard loads, has been progressively developed to carry out modeling of the behavior of plane frame reinforced concrete (RC) and composite structures. By adopting the fiber-beam-element model and the multi-layer-element model, which are developed for RC and composite framed structures, the extreme nonlinear behavior of RC and composite structural elements can be accurately simulated. The technique is an effective tool for the numerical evaluation of the behavior of structures under extreme loading conditions and their collapse mechanisms. Moreover, the proposed model's high simulation capability for the cycle behavior under coupled axial force-bending moment-shear force, the breakdown of structural elements at ultimate states, and the contact between structural elements during the collapse are demonstrated. Finally, the method is used to study the vulnerability of school buildings in Egypt to progressive collapse by conducting a detailed dynamic collapse analysis for an old school building. The analysis is carried out to investigate the cause of the collapse and the method that can be adopted to enhance the structure so that the collapse can be prevented.

Keywords: Progressive collapse, Improved Applied Element Method, Multi Layered Element, School buildings, Retrofitting technique.

1. INTRODUCTION

Reinforced concrete is one of the most widely used modern building materials. With the rapid growth of urban population, RC frame construction has been widely used for residential construction in both the developing and industrialized countries. One of the major causes of seismic vulnerability associated with RC buildings is that, in the developing countries, a large number of the existing RC frame buildings have been designed without engineering input and have been built by inadequately skilled construction workers. This paper considers issues related to earthquake induced progressive collapse of RC buildings in extreme events.

This paper concentrates on developing an efficient numerical technique based on the IAEM. The IAEM is a newly developed method for structural analysis of large-scale steel framed structures (Elkholy and Meguro, 2003) It can trace the behavior of steel structures up to the complete failure stage with high accuracy in reasonable CPU (Elkholy and Meguro, 2004). In IAEM, each structural member is divided into a proper number of rigid elements connected by pairs of normal and shear springs distributed on the boundary line between elements. Unlike the conventional AIM (Tagel-Din and Meguro, 2000), the element in IAEM has been modified in order to use different thickness per each connecting spring to follow the change of thickness of the cross-sectional width in the case of modeling non-rectangular cross-sections.

This research is concerned with the development of an efficient and accurate numerical technique based on the IAEM to analyze the collapse of large-scale RC and composite structures under hazardous loads, such as earthquakes and explosions.

2. MODELING OF RC AND COMPOSITE STRUCTURES USING IAEM

In IAEM, each structural member is divided into several segments. Each segment represents certain cross section properties. A new element type (multi-layered element) is introduced to IAEM to simulate non-homogenous cross sections (Figure 1). This new element is composed of several layers. Each of these layers has its own material properties. All identical layers in the nearby elements are assumed to be connected to each other by sets of normal and shear springs distributed on the boundary line. These sets of springs represent the microscopic material properties of the layer. Moreover, each spring has its own thickness according to the average thickness in the area represented by this spring and its own shear and normal stiffness.

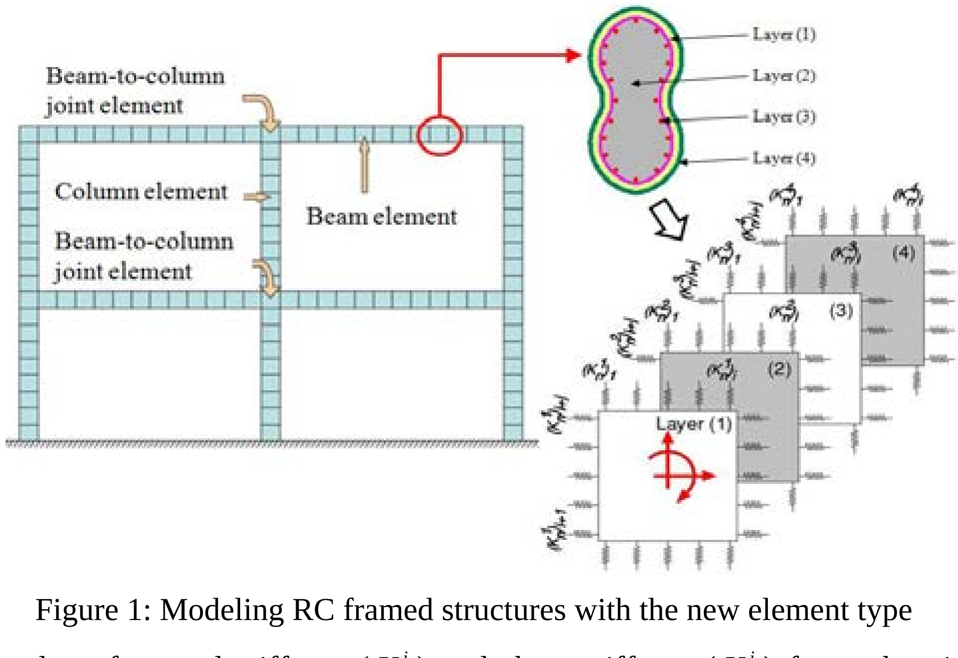


Figure 1: Modeling RC framed structures with the new element type

The value of normal stiffness (K_n^i) and shear stiffness (K_s^i) for each pair of springs in the L^{th} layer can be determined as:

$$(K_n^i)_L = \frac{E_L . d_L^i . (T_n^i)_L}{a} \quad , \quad (K_s^i)_L = \frac{G_L . d_L^i . (T_s^i)_L}{a} \qquad (1)$$

where: the subscripts n and s refer to normal and shear springs, respectively; d_L^i is the distance served by the i^{th} spring in the L^{th} layer; a is the length of the representative area; E_L and G_L are the Young's and shear's modules of the L^{th} layer, respectively; T_n^i and T_s^i are the thicknesses represented by the pair of springs "*i*" for the normal and shear cases, respectively.

The corresponding condensed stiffness matrix of each element is obtained by summing the effects of each spring pair at each layer that the element is composed of. This matrix is then transformed from the local (element) co-ordinate system to the global (structure) co-ordinate system. Equation (2) shows the components of the upper left quarter of the stiffness matrix. All used notations in this equation are shown in Figure 2.

$$\begin{bmatrix} \sin^2(\theta+\alpha)k_n^i + \cos^2(\theta+\alpha)k_s^i & -k_n^i \sin(\theta+\alpha)\cos(\theta+\alpha) + k_s^i \sin(\theta+\alpha)\cos(\theta+\alpha) & \cos(\theta+\alpha)k_s^i L \sin(\alpha) - 2\sin(\theta+\alpha)k_n^i L \cos(\alpha) \\ -k_n^i \sin(\theta+\alpha)\cos(\theta+\alpha) + k_s^i \sin(\theta+\alpha)\cos(\theta+\alpha) & \sin^2(\theta+\alpha)k_s^i + \cos^2(\theta+\alpha)k_n^i & 2\cos(\theta+\alpha)k_n^i L \cos(\alpha) + \sin(\theta+\alpha)k_s^i L \sin(\alpha) \\ \cos(\theta+\alpha)k_s^i L \sin(\alpha) - 2\sin(\theta+\alpha)k_n^i L \cos(\alpha) & 2\cos(\theta+\alpha)k_n^i L \cos(\alpha) + \sin(\theta+\alpha)k_s^i L \sin(\alpha) & L^2\cos^2(\alpha)k_n^i + L^2\sin^2(\alpha)k_s^i + k_n^i \frac{d^2}{12} \end{bmatrix} \qquad (2)$$

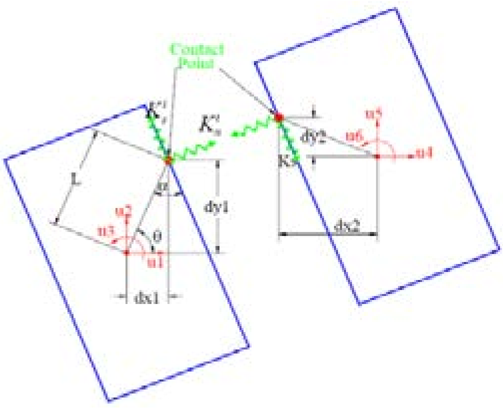
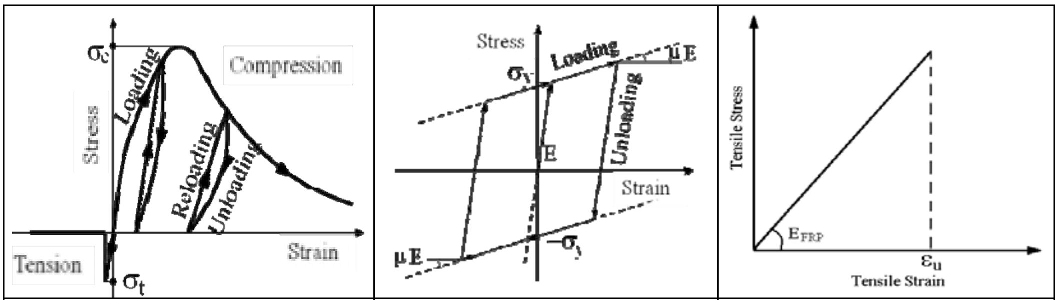


Figure 2: Contact points and DOF

2.1 Material Modeling

The Maekawa compression model for concrete is adopted in the IAEM (Figure 3a). The tangent modulus is calculated according to the strain at the spring location. In tension, the stress-strain curve for concrete is approximately linear elastic up to the maximum tensile strength. After this point, the concrete cracks and its strength decreases gradually down to zero. The steel I-beam and steel bars are modeled as a classical elastic plastic material with strain hardening using bilinear stress–strain relationship in both compression and tension (Figure 3b). Finally, the stress strain relation of all types of FRP material is assumed linear up to failure (Figure 3c).



(a) Concrete	(b) Steel	(c) FRP

Figure 3: Material Models used in IAEM

3. MODIFICATION IN DYNAMIC PROPERTIES

The general differential equation of motion, governing the response of the structure in a small displacement range can be expressed as:

$$[M]\{\Delta\ddot{U}\}+[C]\{\Delta\dot{U}\}+[K]\{\Delta U\}=\Delta f(t)-[M]\{\Delta\ddot{U}_G\} \tag{3}$$

where: [*M*] is mass matrix; [*C*] is the damping matrix; [*K*] is the nonlinear stiffness matrix; *Δf*(*t*) is the incremental applied load vector; $\{\Delta\ddot{U}\}$, $\{\Delta\dot{U}\}$, $\{\Delta U\}$ and $\{\Delta\ddot{U}_G\}$ are the incremental acceleration, velocity, acceleration, and gravity acceleration vectors, respectively.

Equation (3) is solved numerically using an implicit time-stepping method based on the Newmark-Beta technique (Chopra, 2000). In this technique, the displacement, velocity and acceleration vectors at time t are used to obtain a displacement vector after a time interval (Δ*t*) based on the following equation.

$$\left[\frac{1}{\beta(\Delta t)^2}M+\frac{\gamma}{\beta\Delta t}C+K\right]\Delta U=\Delta f+\left[\frac{1}{\beta\Delta t}M+\frac{\gamma}{\beta}C\right]\dot{U}+\left[\frac{1}{2\beta}M+\left(\frac{\gamma}{2\beta}-1\right)\Delta tC\right]\ddot{U} \tag{4}$$

where the parameters β and γ define the variation of acceleration over a time-step and determine the stability and accuracy.

Adopting the multi-layered element in the IAEM allows the user to define material specific weights for each layer, with which the distributed self-mass of the structure can then be obtained using the Materials and Sections facilities. The individual structural mass matrix of each element is calculated assuming that masses lumped at the element centroid. The corresponding lumped mass in each DOF direction is calculated by summing the effect of the small segmental mass represented by each spring considering the change of the springs' thickness. Equation (5) represents the value of lumped mass in each DOF direction. In addition, non-structural mass is added to the model to define any mass not associated to the self-weight of the structure (e.g. slab, finishing, walls, etc).

$$\begin{bmatrix}M1\\M2\\M3\end{bmatrix}=\begin{Vmatrix}\dfrac{a\times b}{nsp}\sum_{i=1}^{i=nsp}\sum_{j=1}^{j=nlyr}\rho_j t_j^x\\ \dfrac{a\times b}{nsp}\sum_{i=1}^{i=nsp}\sum_{j=1}^{j=nlyr}\rho_j t_j^y\\ \sum_{i=1}^{i=nsp}\left(\dfrac{a^3\times b\times\sum_{j=1}^{j=nlyr}\rho_j t_j^x}{12\times nsp^2}+\dfrac{a\times b^3\times\sum_{j=1}^{j=nlyr}\rho_j t_j^y}{12\times nsp^2}\right)\end{Vmatrix} \tag{5}$$

where: *a* and *b* are the element dimensions; ρ_j is the density of material of the j^{th} layer considered; *nlyr* is the number of layers; *nsp* is the number of connecting springs; m_i^x and m_i^y are the i^{th} spring mass per unit area of the element in x and y directions respectively; and t_j^x and t_j^y are the i^{th} spring thickness at a certain level in the j^{th} layer in x and y directions respectively.

4 ASSESSMENT OF OLD EXISTING SCHOOL BUILDINGS

The vulnerability of schools and other educational facilities has been observed in every recent destructive earthquake all over the world. The work in this section aims to identify the causes of the collapse of one of the typical types of old existing school buildings in Egypt to evaluate its seismic risk, to evaluate the efficiency of different retrofitting techniques, and to propose a national and public policies to reduce the risk of this type of schools. In this section, the multi-layered IAEM is applied to investigate the validity of the proposed method in simulating progressive collapse of RC school buildings under hazardous load conditions. A detailed analysis of the collapsing process of the selected structure with and without retrofitting under severe ground motion conditions is presented.

4.1 School buildings in Egypt

School buildings in Egypt are typically one to five-storey long narrow buildings with an open corridor on the school courtyard side and classrooms on the longitudinal side. The courtyard side of a classroom typically has large windows; and the back wall is solid up to about 70 cm from the upper floors, where long and narrow longitudinal windows are located to allow for ventilation and extra lighting. School class blocks are often aligned in an L-shape or U-shape around the school courtyard. The typical structure consists of a moment resistant concrete frame in the longitudinal direction and a concrete frame with unreinforced masonry infill walls in the transversal direction.

4.2 Structural modeling and verification

Figure 4 shows the concrete dimensions and reinforcement details of one of the typical school buildings that were designed and constructed according to the Egyptian specifications issued before the October 1992 earthquake. The structure consists of a series of single bay, 3-story RC frames with a cantilever. Using the multi-layered element features, the school building was modelled using only 87 elements for the superstructure. Moreover, three retrofitting techniques for this type are also investigated using the same number of elements (Figure 5).

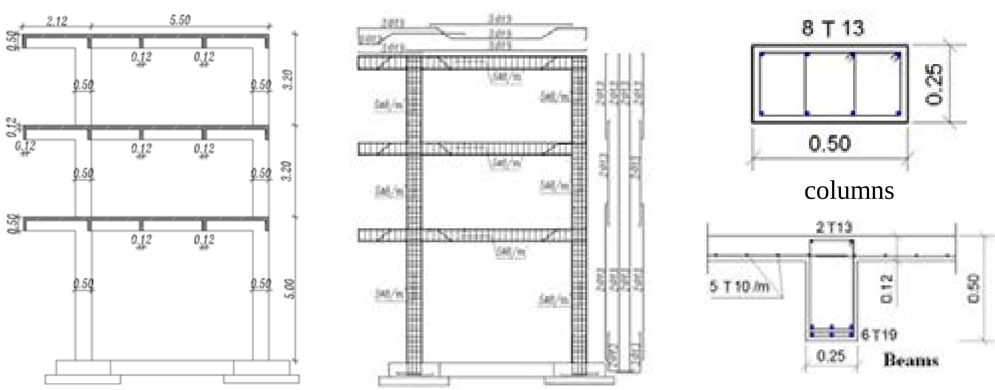


Figure 4: Concrete dimensions and reinforcement details

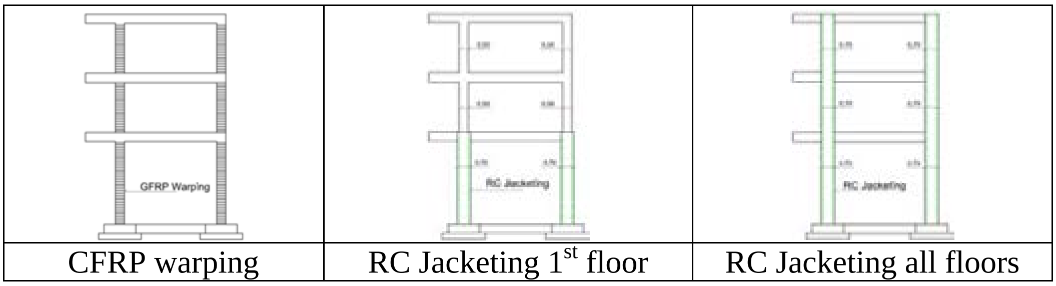


Figure 5: The three proposed retrofitting techniques

To evaluate the accuracy of the modelling, the frame is simulated both in IAEM and SAP2000 (CSI, 2000). A modal analysis was performed to calculate the natural frequencies of the structure. The first three modes are basically coincidentally close and a maximum difference of 7.26 % has been observed. These three mode shapes are shown in Figure 6.

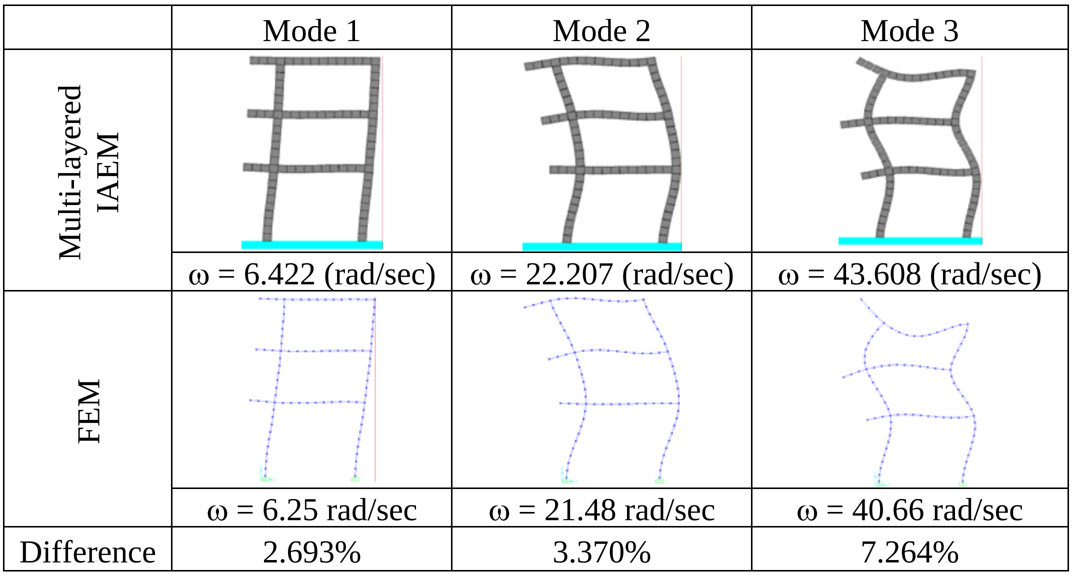


Figure 6: Comparison between the first three modes obtained by IAEM and FEM

4.3 Seismic response

After verifying the method, the inelastic dynamic collapse analysis has been performed by introducing a displacement time history of three ground motion records at the supports, as shown in Table 1. The acceleration time history and 5% damping elastic response spectra curves of the selected ground motions with the buildings fundamental periods illustrated on the curve by vertical lines are shown in Figure 7 which shows a distinctive difference among each ground motion. Each record has been scaled up and down to different levels in order to determine the PGA value at which a certain building type can resist without collapse.

Table 1: Ground motions characteristics

Earthquake	Date	Component	PGA (g)	PGV (cm/s)	PGD (cm)	A/V
Kobe	16/1/1995	KAK090	0.345	27.6	9.6	1.247
Northridge	17/1/1994	NWH090	0.583	75.5	17.57	0.772
Park field	28/6/1966	C02065	0.476	75.1	22.49	0.634

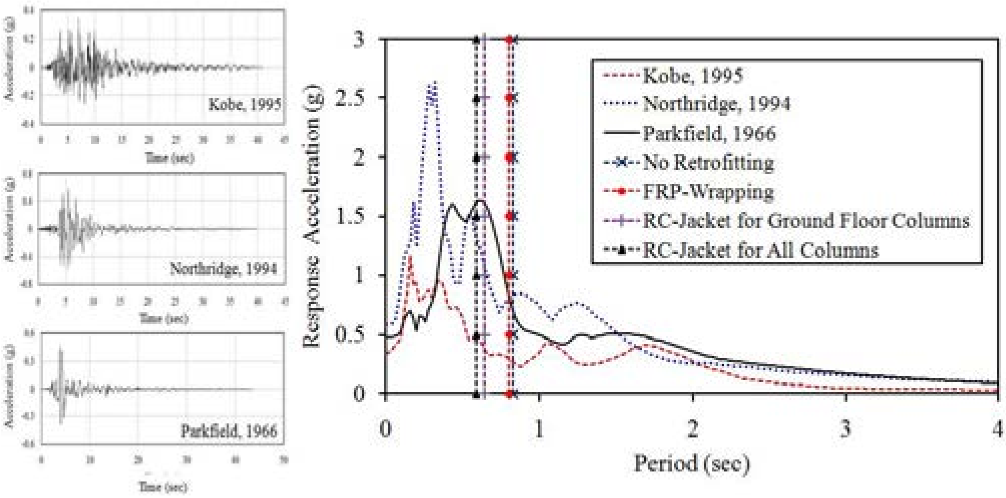


Figure 7: Selected ground motions and their response spectrum

4.4 Analysis results

The main objectives of the assessment are to investigate the collapse mechanism of each model and to obtain the minimum value of the PGA of each ground motion record used in this analysis that can produce the collapse. These minimum values are used to evaluate the vulnerability of each model and to assess the efficiency of each retrofitting strategy. Figure 8 summarizes the results of the analysis for the un-retrofitted and the retrofitted models. The figure demonstrated that the un-retrofitted school building has a very poor performance in the short direction (investigated direction). Therefore, even a small magnitude earthquake posed a threat. It was also founded that retrofitting the columns by CFRP warping increased the seismic capacity by around 40%, however, using RC jacketing increased the seismic capacity of the building by at least 80% to 150% based on the height of the jacketing.

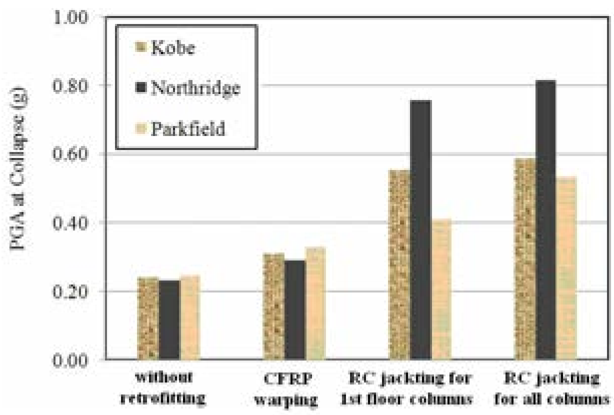


Figure 8: Minimum values of the PGA that produced complete collapse

Figure 9 shows the seismic collapse mechanism of the un-retrofitted school. The figure shows that the collapse initiated at the mid of the ground floor column due to combined actions of axial and flexural moments. The insufficient ductility of the members due to insufficient confinement, and low level of strength due to insufficient cross-sectional dimensions, longitudinal reinforcement ratio and low strength of longitudinal bars were the main reasons of the failure.

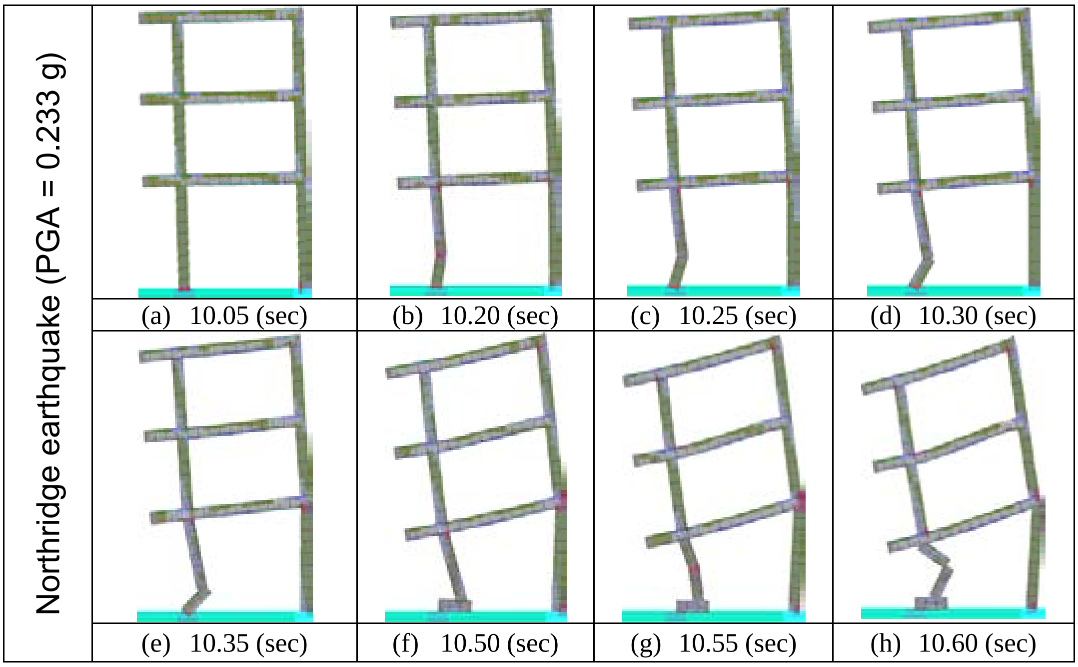


Figure 9: Collapse mechanism of the building without repair

The rehabilitation using *FRP*

Figure 10 illustrates the enhancement in the columns capacity due to using CFRP warping which increased the resistance capacity of the building. The FRP composite materials do not significantly affect the initial stiffness of the concrete members but improves the strength. Therefore the rehabilitation using FRP warping for the columns does not significantly change the dynamic response of the frame. FRP-strengthening significantly changes the damage location and the collapse mechanism of the frame.

The rehabilitation using *RC jacketing*

The effect of using RC jacketing for columns in the first floor only is shown in Figure 11. However, the seismic capacity of the building increased by more than 80%, Figure 11 shows one of the undesirable collapse mechanisms. Due to the sudden change of the cross-section of columns, the building had a non-ductile soft-story collapse mechanism at the second floor level. The max story deformation occurs at the second story and plastic hinges developed at the ends of columns.

Finally the analysis shows that using the RC jacketing for all columns in all floors improves the seismic performance of the structure (Figure 12). According to the figure, the inelastic deformation demand and energy dissipation spread throughout the structure. Beams commence yield before columns and a beam side-sway mechanism occurred. Plastic hinges form at critical sections of all beams in the frame and the bottom of the first story columns.

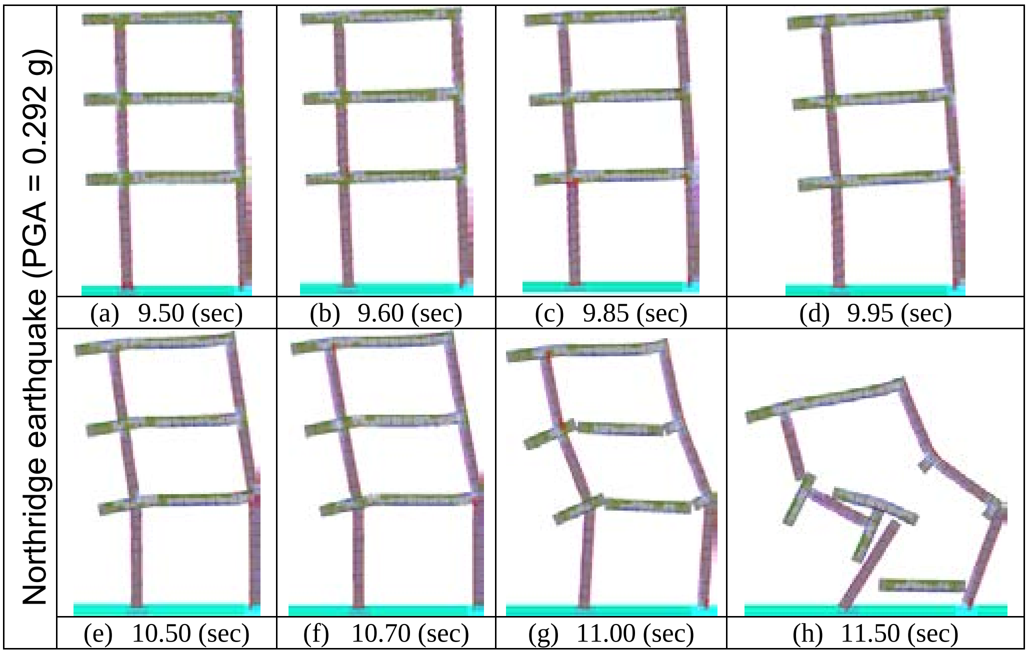


Figure 10: Collapse mechanism of FRP Retrofitted building

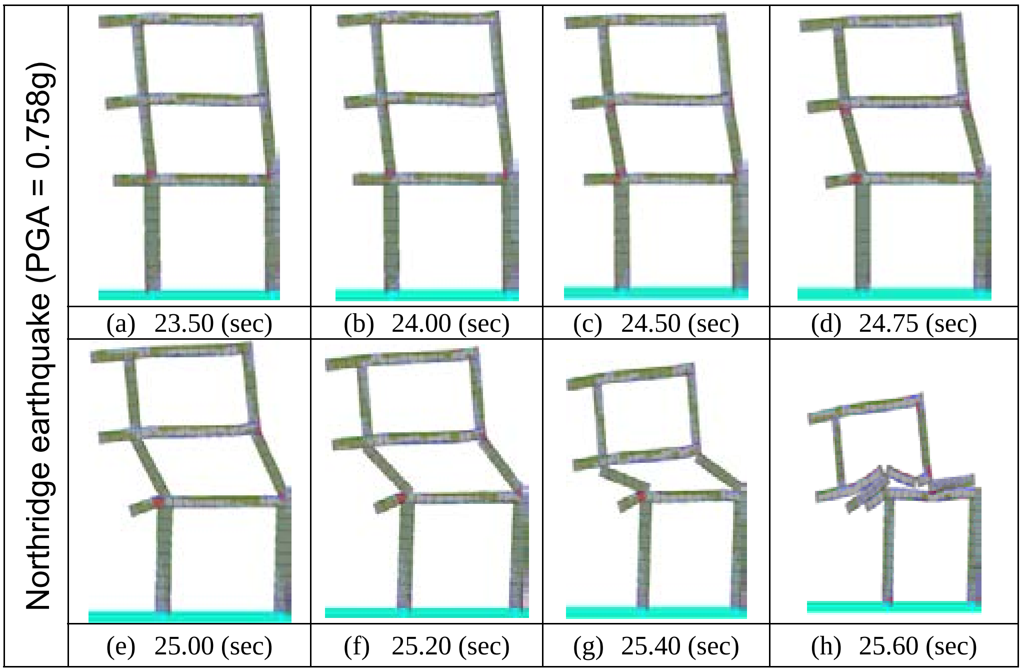


Figure 11: Collapse mechanism of the building with RC jacketing columns in the ground floor only

5. CONCLUSIONS

The numerical method, IAEM, presented in this paper shows a good capability to study the total behavior of RC and composite structural buildings from the early stage of loading until the total collapse occurs. The analysis demonstrated the

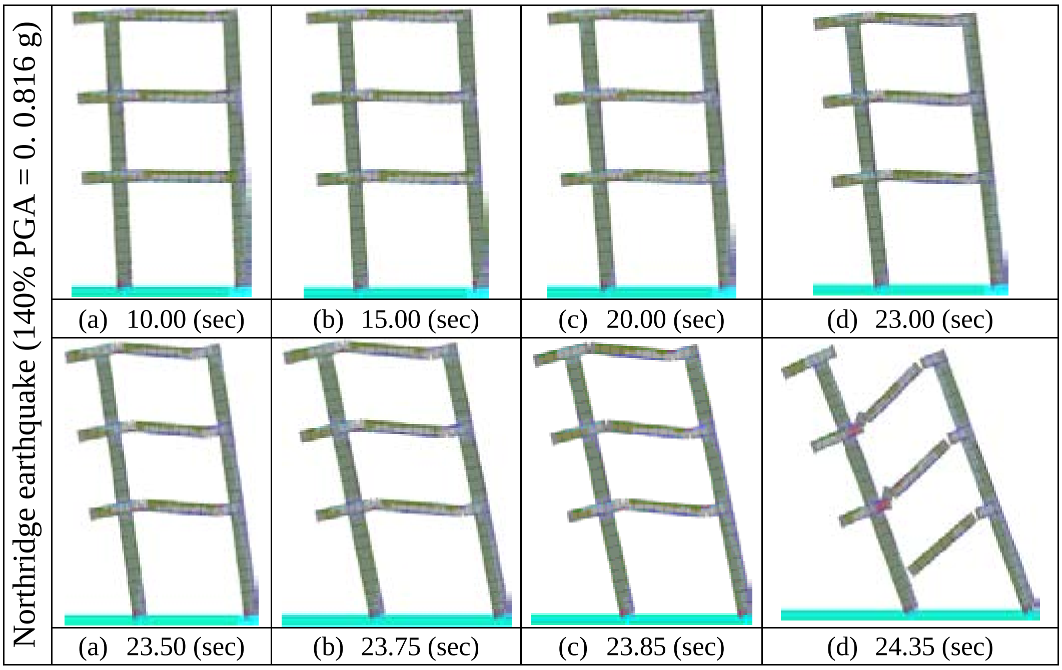


Figure 12: Collapse mechanism of building with RC jacketing in all floors

reliability of the new IAEM in modeling large scale RC framed structures using the minimum number of elements. The validity of the developed code has been demonstrated by a numerical example. Moreover, less computational effort and a wider applicability for structural analysis have been observed than those of conventional discrete element methods. The proposed method can provide a better understanding of the failure mechanism of buildings due to severe ground motions. Simple two-dimensional analysis tools such as that adopted in this paper can be used to judge in a qualitative and quantitative manner the damage tolerance of buildings. Evaluation of the seismic performance of a sample of old existing school buildings in Egypt is presented. Approaches to reduce the vulnerability of the building are also highlighted.

REFERENCES

Elkholy, S., H. Tagel-Din, and K. Meguro. Structural Failure Simulation due to Fire by Applied Element Method. in The 5th Japan Conference on Structural Safety and Reliability. 2003. Tokyo, Japan.

Elkholy, S. and K. Meguro. Numerical Simulation of High-rise Steel Buildings using Improved Applied Element Method. in 13th World Conference on Earthquake Engineering. 2004. Paper No. 930, Vancouver.

Tagel-Din, H. and K. Meguro, Applied Element Method for Simulation of Nonlinear Materials: Theory and Application for RC Structures. *Structural Engineering and Earthquake Engineering*, 2000. 17(2): p. 137-148.

Sap2000 v.12, Structural Analysis Program, Computers and Structures, Inc., CA., USA, 2000

Chopra, A.K., 2000. Theory and Applications to Earthquake Engineering. 2nd edition, ed. P.H. Education.: Prentice Hal

Influence of segregation with execution for quality variation of cover concrete

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ABSTRACT

The quality of cover concrete, which is affected by the execution conditions of construction works such as casting and consolidation method, strongly influences the durability of concrete structures. Currently, the quality of the structural concrete is confirmed by examining fresh concrete properties and the compressive strength of test pieces, but these examinations do not evaluate the durability of the structural concrete directly. It is more effective to directly evaluate the durability index of cover concrete to ensuring the durability of structure. One of these methods is the non-destructive air permeability test which can be utilized in the field, but it is not clear what effect the execution conditions of construction works may have on the variations in cover concrete. The purpose of this study is to evaluate the influence of the execution condition of construction works on the cover concrete quality. Causes of quality variation include the segregation of fresh concrete, which occurs when the ratio of coarse aggregate and mortar changes due to excessive vibrations or the blockage by steel-bar, and bleeding after completion of casting. This study investigates the influence of vibration time, arrangement of steel bar, and change of mix proportions on quality variations. Additionally, when the mix proportion is changed, the fresh performance such as bleeding and air permeability after hardening is also examined. In this study, quality of cover concrete is evaluated by the air permeability index, void content, rebound number, and compressive strength. The results found that although the compressive strength of concrete itself can be understood by the water-cement ratio, air permeability index may vary even when the water-cement ratio is the same. The bleeding ratio is influenced by the change in mix proportion, and a high degree of influence was observed for high slump concrete.

Keywords: cover concrete, execution, vibrating consolidation, segregation

1. INTRODUCTION

Durability of concrete structures depends on the mass transfer resistance of cover concrete, which is a primary factor in deterioration due to chloride ion and carbon dioxide, oxygen, water. Therefore, the quality of the cover concrete is very important for ensuring the concrete structures' durability. The quality of cover concrete is influenced by factors other than the water-cement ratio, especially the execution conditions of works such as the consolidation and curing method, and the relative influence is different for constructive quality of fresh concrete such as workability and consistency.

Currently, the quality of structural concrete is confirmed by examination of the fresh condition, such as slump, and the compressive strength of test pieces. However, these examinations do not evaluate the durability of the structural concrete directly, and the influence of execution condition of work is uncertain. If the evaluation of quality of cover concrete, such as permeability, could be conducted directly on the structures, it would be very effective for ensuring durability (JSCE, 2007).

The purpose of this study is to evaluate the influence of the execution condition of construction works on cover concrete quality. One of the causes for the quality variations is the segregation of fresh concrete, which is affected by the ratio of coarse aggregate, mortar change by excessive vibrations, obstruction by steel-bar, and bleeding after casting completion. This study investigates the influence of vibration times and arrangement of steel bar for quality variations in Section 2. In addition, the fresh performance such as bleeding and air-permeability after the hardening at various mix proportions is examined in Section 3.

2. EXPERIMENTS WITH LARGE-SCALE SPECIMENS

2.1. Test procedure

Mix proportions are given in Table 1. In this study, ready mixed concretes which satisfy JIS A 5308 were used. Two types of concrete with different slump were investigated. The water-cement ratio of these mix proportions was set at 57.0%. The slump for water unit weight of 180 kg/m^3 was 18.0 cm, whereas the slump for water unit weight of 159 kg/m^3 was 8.0 cm. Table 2 shows the test results for fresh conditions. The bleeding content and ratio of 24-18-20N is larger than that of 24-8-20N.

Table 1 Concrete mix proportions

No.	Concrete Type	Air (%)	W/C (%)	s/a (%)	Unit Weight(kg/m^3)				
					W	C	S	G	Ad.
1	24-8-20N	4.5	57.0	46.6	159	279	858	1002	2.79
2	24-18-20N	4.5	57.0	49.3	180	316	866	906	3.16

※1 :Strength-slump-Maximum Aggregate Size (Cement type)

※2: AE water reducing agent

Table 2 Fresh conditions test results

Concrete Type	Slump cm	Air %	Concrete Temp. (°C)	Bleeding Content (cm^3/cm^2)	Bleeding Ratio (%)
24-8-20N	6.5	4.9	17.1	0.074	1.85
24-18-20N	16.0	5.3	16.0	0.148	3.58

※Bleeding content and ratio(JIS A 1123: Bleeding of concrete)

Figure 1 illustrates the full-scale specimen dimensions and reinforcing steel bar arrangement. Specimen dimensions are similar to the original structure at 0.9×0.9×1.2m with reinforced (both form sides) and non-reinforced cases in order to investigate the influence of reinforcing steel bar on cover concrete quality. The side surface was also investigated for some specimens.

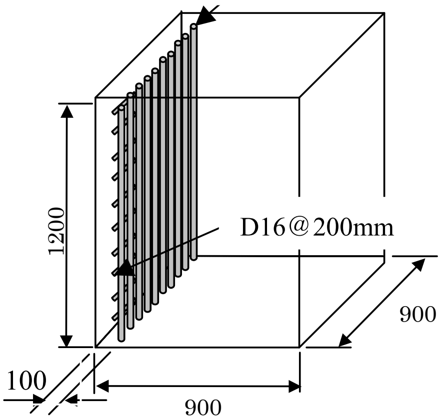

Figure 1 Full size specimen dimensions and rebar arrangement

Table 3 shows the construction works and specimen conditions. Concrete was cast using a concrete pump-piston and consolidated with a high-frequency vibrator of ϕ 50 mm. Vibration time is 15 seconds for standard construction works, and was determined from experience and compressive strength. In addition to the standard time, 45 seconds vibration case was also investigated to examine the most suitable vibration time for concrete quality of fresh condition. After curing specimens were exposed to a warm outdoor environment unaffected by chloride ions.

Table3 Construction works and specimen condition

	Execution Condition and Parameter
Casting speed	2 to 3 m/h
Vibration times	15 seconds(Standard vibration)
	45 seconds(Excessive vibration)
Curing times	5 days (removed form)

Table 4 shows the test items and methods. Air permeability was tested by the non-destructive Torrent method which can also be used in the field (Torrent, 1992). This method uses a two-chamber cell, with an inner and outer chamber, based on the guard-ring principle. The coefficient of air permeability by Torrent method (KT) is computed by following numerical formula.

$$KT=\left(\frac{Vc}{A}\right)^2 \frac{\mu}{2\epsilon Pa}\left[\frac{\ln\left(\frac{Pa+\Delta P\tau}{Pa-\Delta P\tau}\right)}{\sqrt{t}-\sqrt{t0}}\right]^2 \quad (1)$$

KT : Coefficient of air-permeability-Torrent method(m2)
V_C *: Volume of inner cell system(mm^3)*
A : Cross-sectional area of inner cell (mm^2)
μ *: Viscosity of air (Ns/m^2) (2.0×10^{-5})*
ε *: Estimated porosity of the cover concrete(m^3/m^3) (0.15)*
Pa : Atmospheric pressure(N/m^2)
⊿P : Times(s) at the end of the test(N/m^{-2})
T : Times(s) at the end of the test
T_0 *: Times(s) at the beginning of the test(=60s)*

Testing of the full-scale specimens examined air permeability at the concrete surface. Void content and apparent density was measured for specimens by taking drilled cores considering segregation in concrete materials. These examinations were tested at each three points in the upper, middle, and lower areas of specimen.

Table 4 Tests items and method

Tests items	Test method
Air permeability	Torrent method (Torrent, 1992)
Apparent density Void content	ASTM C 642 Weight method (Core specimens)

2.2. Test results and discussion

Figure 2 shows relationship between KT (the coefficient of air permeability) results and specimen height. Comparing reinforced and non-reinforced results in the case of slump 8cm, it can be seen that for reinforced specimens the air permeability in all areas of the specimens are fairly similar, whereas for non-reinforced specimens measurements in the upper area tended to be larger than the middle and lower areas. This is because the concrete is affected by consolidation due to self-weight and bleeding. This effect wasn’t seen in the case of reinforced concrete because the reinforcing steel-bar affected the self-load of the cover concrete.

For the vibration times, vibrating for 45 seconds resulted in lower air permeability than the 15 seconds standard vibration time used in real construction works. The fact that air permeability at the concrete surface decreased for long vibration times suggests that the vibration time appropriate for permeability is different than that appropriate for compressive strength for the concretes used in this study.

Whereas, in the case of 18cm slump, KT for both reinforcing and non-reinforcing tended to be larger than those of 8cm slump, and upper areas are larger than middle and low areas.

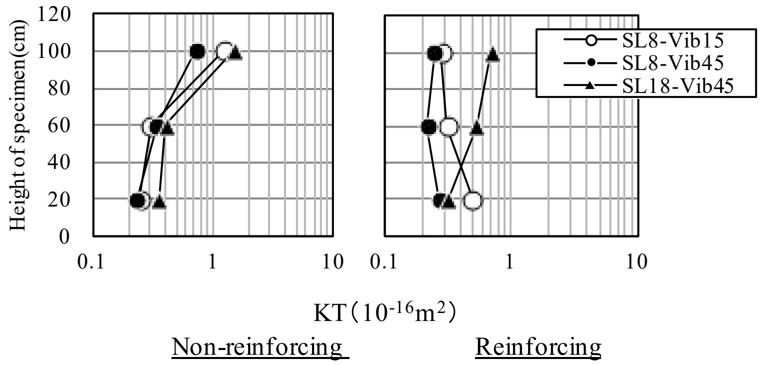

Figure 2 Relationship between KT and height of specimen (Tested at 91 days)

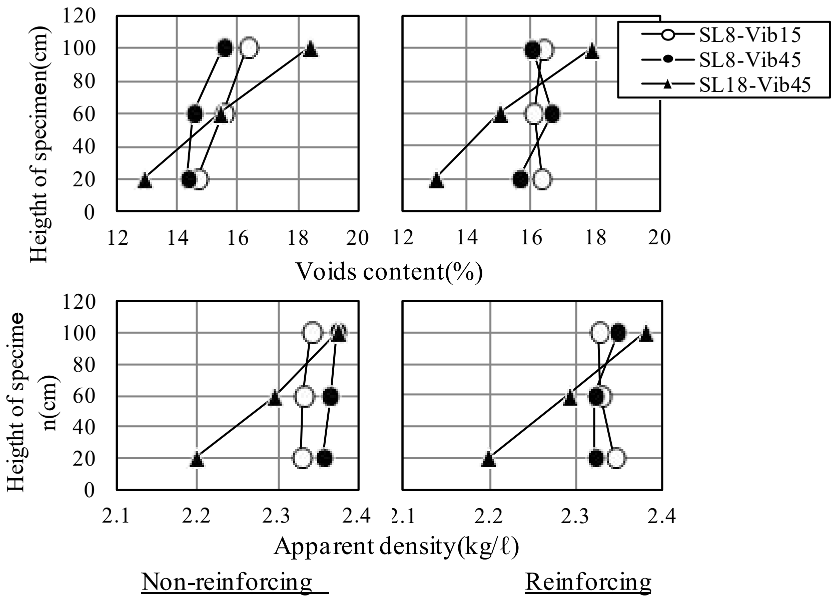

Figure 3 Relationship between void content or apparent density and height of specimen(Tested at 91 days)

Figure 3 shows relationship between void content, apparent density and specimen height. The test results of void content and apparent density are similar to air permeability in that for the reinforcing of 8cm slump the difference by specimen height is small, and in the case of 18cm slump it is large.

In this study, since the condition of curing is same in all case, the change of void content and apparent density was caused by the change of course aggregate quantity by excessive vibrations, and pass through obstacle of steel-bar, and the bleeding after the casting completion.

Figure 4 shows between apparent density and ratio of unit coarse aggregate weight, unit water weight by calculation of mix proportion. Here, the ratio = 1.0 is standard mix proportion, and under the condition that assume ratio of the other material uniformity, it was changed unit weight of coarse aggregate or water. We see from Figure 4 that for the density change, the influence of the coarse aggregate change is large. Comparing the test results of apparent density and ratio of unit coarse aggregate, ratio of unit coarse aggregate in the each case appear in Table 5. In the case of 8cm slump, the influence of excessive vibration against segregation of coarse aggregate tended to be small, but in the case of 18cm slump it was large. In general, since the decrease in quantity of coarse aggregate (increase of mortar quantity) influences void content, this relationship agreed with test results.

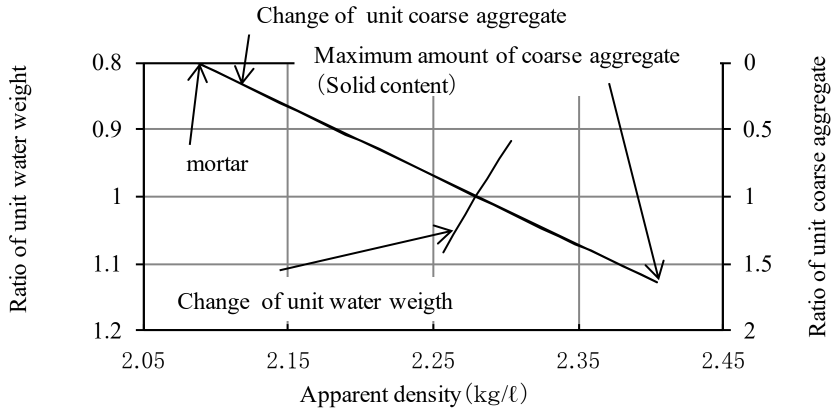

Figure 4 Relationship between apparent density and ratio of unit coarse aggregate weight, unit water weight

Table 5 Test results of apparent density
and estimated results of ratio of coarse aggregate

Concrete type	Vibration	Apparent density(kg/ℓ)				Ratio of coarse aggregate		
		standard (Test piece)	Measured value					
			Min	Max	Range	Min	Max	Range
24-8-20N	standard	2.32	2.31	2.37	0.06	0.93	1.22	0.29
24-8-20N	excessive	2.32	2.29	2.37	0.08	0.86	1.25	0.39
24-18-20N	excessive	2.28	2.17	2.39	0.22	0.43	1.57	1.14

As shown in Section 2.1., KT is calculated by the equation (1). In general, since the accurate porosity (ε) of the cover concrete cannot be known at the time of examination, ε in the equation is calculated using constant value (0.15). Here, given that the porosity is determined by mortar in the concrete, the estimated porosity can modify KT relative to standard mix proportions.

Figure 5 shows the relationship between modified KT and specimen height. If the reason why change of coefficient of air permeability is that mortar quantity is changed, then this relationship should not change for specimen height. But also in this case, the modified KT for upper area tended to be larger than middle and low areas. The reason for this is that concrete quality is changing by influence of bleeding, and may be influenced by segregation.

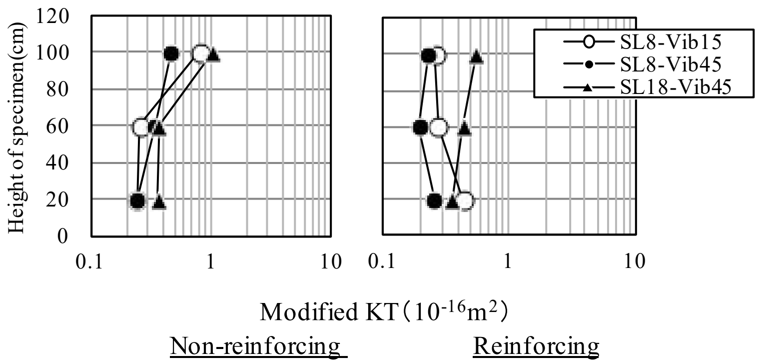

Figure 5 Relationship between modified KT and height of specimen

3. EXPERIMENTS ON COARSE AGGREGATE SEGREGATION

3.1. Test procedure

Mix proportions are given in Table 6. These mix proportions are intended to evaluate material segregation of mortar and coarse aggregate in the concrete, therefore the quality of mortar is constant and the ratio of coarse aggregate is changing from 0 (mortar) to 1.21 (standard is 1.0).

The concrete manufactured at 20 ℃ in a laboratory, and the slump, air and bleeding test of fresh concrete were examined. The test pieces cast were φ10× 20cm (compressive strength, mortar: 5 × 10cm) and 15 × 15 × 15 cm (air permeability at the concrete surface). These pieces were exposed to 20ºC and 60% RH after sealed curing until 5 days, and the test for compressive strength and air permeability was examined at 28 days.

Table 6 Concrete mix proportions

W/C	Air	s/a	Ratio of G	Unit Weight (kg/m^3)				
%	%	%		W	C	S	G	Ad.
55	7.1	100	0.00	270	491	1294	0	1.23
55	5.2	57.8	0.73	197	357	949	705	0.89
55	4.5	46.5	0.99	170	309	821	963	0.77
55	3.9	38.3	1.21	148	270	716	1175	0.68

Standard mix proportions

3.2. Test results and discussion

Figure 6 shows the change in ratio of coarse aggregate and compressive strength or coefficient of air permeability. In the figure, KT (modified porosity) was modified estimated porosity following ratio of coarse aggregate. The compressive strength tended to be constant without the influence of coarse aggregate quantity. Here, the reason why in the case of change ratio 0 (mortar) the compressive strength is a little larger than other case is that it seems to be influenced by the test piece dimensions. On the other hand, in the case of coarse aggregate change, the coefficient of air permeability can be seen larger than those of standard concrete. This relationship is similar in the case modified estimated porosity.

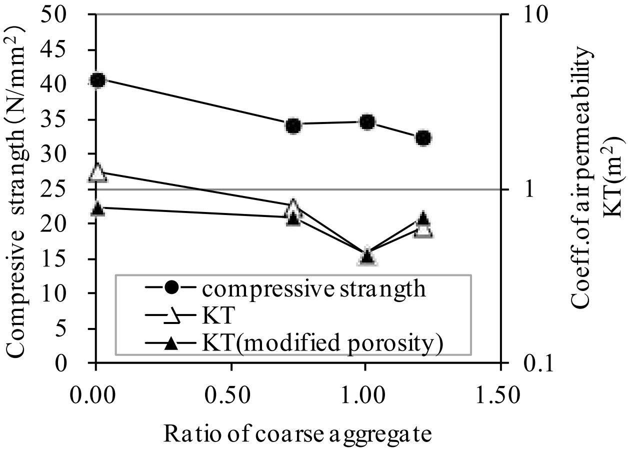

Figure 6 Relationship between ratio of coarse aggregate and compressive strength, coefficient of air permeability

Figure 7 shows the bleeding test results. When changing the ratio of coarse aggregate, the bleeding ratio tended to be larger than standard mix proportion. The fact that this tendency is similar to coefficient of air permeability suggests that air permeability is more easily affected by bleeding than compressive strength.

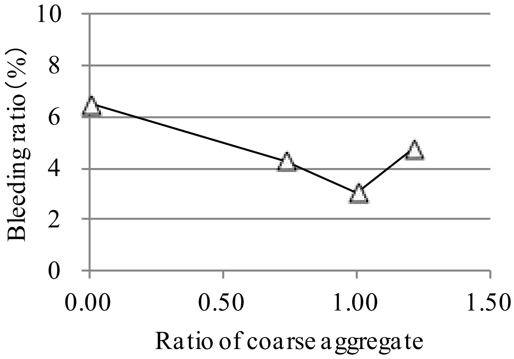

Figure 7 Relationship between change ratio of coarse aggregate and bleeding ratio

In general, in the case of non-segregation, the quality of cover concrete changes in the height direction by bleeding of concrete by casting and vibration. In addition, if the segregation of mortar and coarse aggregate occurred by construction process such as excessive vibration, the quality of the fresh concrete changes bleeding ratio. As a result, the change of the height direction may become larger than non-segregation case. It should be noted that segregation such as aggregate settling due to vibration occur for concretes with high slump which are consolidated by excess vibration.

4. CONCLUSION

This study carried out an experimental investigation to evaluate the influence of vibration and segregation on the quality of cover concrete for ensuring the durability of structure concretes. The conclusions of this study are as follows:

1) For reinforced specimens, the changes of air permeability in height direction of the specimens are smaller than non-reinforced specimens. This is because the concrete is affect by consolidation due to self-weight and bleeding.
2) For concrete with 8cm slump, the air permeability index tended to decrease for vibration times longer than the standard method. However for concrete with 18cm slump, the air permeability index tended to increase with excessive vibration due to segregation of coarse aggregate and mortar.
3) The compressive strength was not affected by segregation of coarse aggregate and mortar. On the other hand, the air permeability of concrete was more easily affected by the segregation due to change of bleeding property of segregated concrete and mortar quantity.

ACKNOWLEDGEMENT

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REFERENCES

Torrent, R.J.,1992, A two-chamber vacuum cell for measuring the coefficient of permeability to air the concrete cover on site, *Materials and Structures*, Vol. 25, pp.358-365

Japan Society of Civil Engineers, 2008. Concrete engineering series80, Sub-committee on the verification system for surface quality and durability performance of RC structures

Fatigue damage estimation of RC beams under cyclic loading

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ABSTRACT

In Japan, the deterioration of some concrete structures constructed in 1960s is beginning to be detected. In the future, maintenance costs for deteriorated structures will steadily increase, so the quantitative evaluation of deterioration degree will become an important task. In this study, the fatigue damage estimation method of reinforced (hereafter referred to as "RC") beams subjected to cyclic loading is discussed through loading tests of specimens in laboratory.

In the proposed method, the damage progress – the degradation of flexural stiffness – is modeled by the correlation between increasing deformation due to cumulative cyclic loading and residual deformation caused by cyclic creep. The deformation is represented by the curvature obtained by the measured strain of extreme compressive fiber and reinforcing bar. Using the proposed method it may be possible to carry out quantitative evaluation of safety for limit values, e.g. yielding or compression failure.

Keywords: cyclic load, fatigue, cyclic creep, flexural stiffness

1. INTRODUCTION

A large number of concrete bridges were constructed since the era of high economic growth in Japan. The numbers of concrete road bridges, i.e., reinforce and pre-stressed concrete bridges, with span length longer than 15m is about 71,000 (MLIT, 2002). Since most of the bridges constructed before the upgrade of design load up in 1995, it seems that the number of deteriorated bridges may increase owing to the increase of traffic and vehicle weight in recent years. So the evaluation of the soundness of existing concrete bridges will be becoming an important task to decide whether a bridge is still in serviceable condition or not.
Currently, the maintenance of concrete road bridges is carried out mainly by periodic visual inspections. On the basis of the inspection results, the degree of deterioration and the main cause of deterioration are determined. In this process, however, it is difficult to evaluate the safety, serviceability, and especially fatigue, which are the criteria mentioned in Standard Specification for Concrete Structures (JSCE, 2002). So in this study, the quantitative estimation method related to the

fatigue under cyclic loading is discussed for RC beam structures like bridge main girders. To deal with this problem, the cyclic loading test in laboratory was carried out to clarify the progress of fatigue.

2. LOADING TEST OF SPECIMENS IN LABORATORY

2.1 Outline of loading test

In order to clarify the estimation method and the measurement one in situ for fatigue progress of RC beams, the cyclic loading test of specimens were carried out in laboratory.

Details of specimens are shown in Figures 1 and 2. And outline of tension reinforcement is summarized on Table 1. The beams were 3400 mm long, 200 mm wide and 300 mm thick and were simply supported over a span of 3000mm. The flexural and shear reinforcement was designed to ensure flexural failure. Stirrups of 10mm diameter were placed in the beam as shear reinforcement at spacing of 200mm.There was a 40mm clear cover of concrete. The compressive strength of concrete was 30.4 MPa whereas the yield strength of steel was 399MPa.

The tests were carried out using a 294 kN capacity hydraulic servo actuator as shown in Figure 3. The actuator was operated under load control. And the load of sin wave type was applied. Increasing the maximum value of load, the loading for each the maximum was continued until the crack propagation converges, as shown in Tables from 2 to 4.

Strains of reinforcement bar, concrete of extreme compressive fiber and deflections at mid-span were recorded during testing.

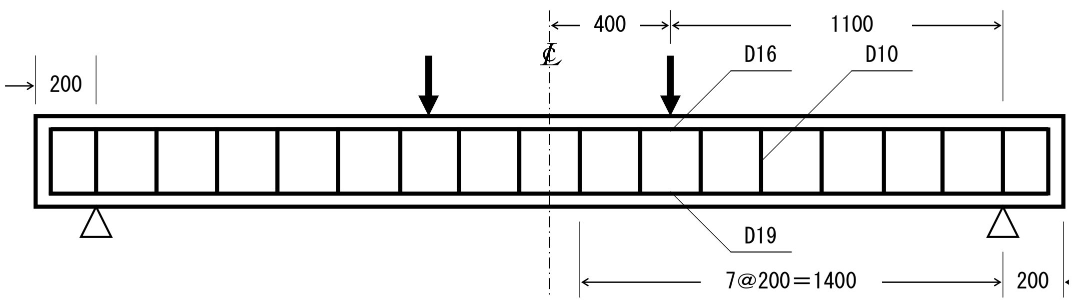


Figure1:Details of test beam (unit：mm)

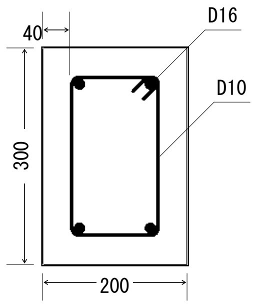


Table1:Type of tension steel

No.	Tension Reinforcement	Tension Steel Ratio (%)
1	2-D16	0.66
2	2-D19	0.90
3	2-D22	1.29

Figure2:Closs-sction of test beam

Tabel2: Loading of Specimen No.1

Maximum Load (kN)	Number of Cycle	Loading Rate (Hz)
6.9	50,000	1.5
16.7	50,000	1.0
36.3	30,000	
46.1	61,000	0.5
51.0	10,000	

Table3: Loading of Specimen No.2

Maximum Load (kN)	Number of Cycle	Loading Late (Hz)
6.9	6,000	1.0
16.7	30,000	
36.3	20,000	0.75
66.6	100,000	0.50

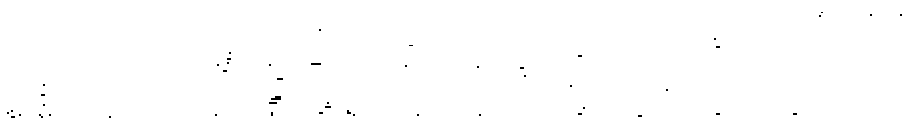
Table4: Loading of Specimen No.3

Maximum Load (kN)	Number of Cycle	Loading Rate (Hz)
6.9	20,000	1
16.7	100,000	1
36.3	50,000	1
75.5	80,000	0.5
85.3	5000	0.5
91.2	10,223	0.5

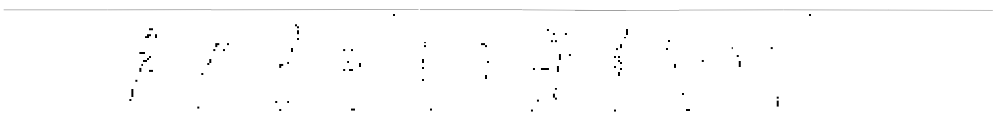
Figure3:Test set-up

2.2 Experimental Results

The state of cracks after test of each specimen is illustrated in Figure 4. The number and spacing of cracks becomes grater with the amount of reinforcement. The relation between residual and elastic deflection at mid span before the yield of reinforcement shown is shown in Figure 5. In this diagram, the data of the first cycle and the last of cycle for each the maximum load. And the elastic deflection is defined as the division of increment deflection by the load for a cycle loading. Due to crack growth, the deterioration of flexural stiffness occurs. As a consequence, the deflection increased. Furthermore, the increase of residual deflection was becoming greater than the increment of elastic deflection owing to the damage in compression. The damage in compression is represented by the relation between plastic and maximum strain as shown in Figure . The elasto-plastic and damaging model (Maekawa et al.,2009) is also shown together by solid line.



(a)No.1



(b)No.2

(c)No.3

Figure4: Cracks after test

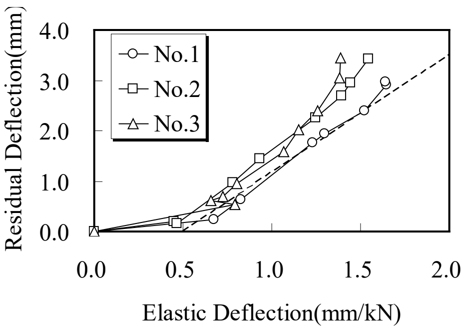


Figure5: Residua land elastic deflection diagram

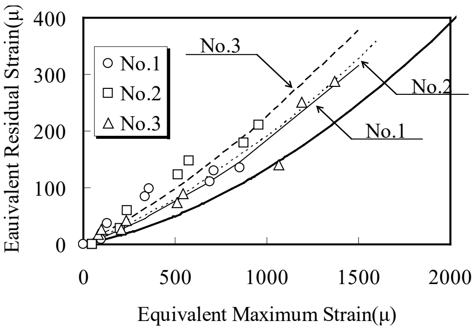


Figure6:Residual and total strain at compression top fiber

3. FATIGUE DAMGE EVALUATION

3.1 Estimation of Cross Section Curvature

According to the analogy of the elasto-plastic and damaging model, in this study, the fatigue damage of beams is evaluated by the use of the residual and the maximum deformation. In order to evaluate the decline stiffness of members by deformation, in general, both of load and deformation have to be observed simultaneously. However, the load observation in situ seems to be expensive. To avoid this problem, therefore, the curvature, which is one of the criteria of deformation, under a certain constant strain in compression top fiber will be utilized in this study.
The curvature of the observed cross-section is evaluated using the strain of compression top fiber and reinforcement under in-place hypothesis as illustrated in Figure 7.

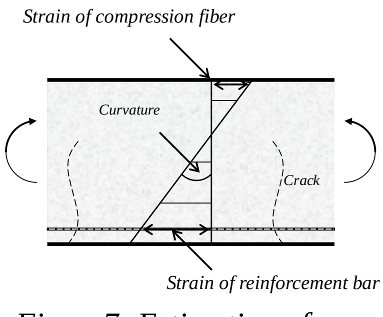


Figure7: Estimation of curvature

And the reinforcement strain is estimated using the crack width observed by pai-gage as follows;

$$\varepsilon_s = \frac{w}{1.1 \cdot l_c}$$

where, ε_s : strain of reinforcement bar

w : crack width

l_c : crack spacing

In view of simplicity of measurement in situ, the maximum crack width of all cracks is adopted for the estimation of reinforcement strain in this study. The comparison of the estimation results of reinforcement strain estimated by maximum crack width with observed strain by strain gage at mid span is shown in Figure 8. The gradient of regression line is different among specimens. However, it is possible to adopt for the stiffness degradation estimate of each specimen, because the linearity is held until the yield of reinforcement. The difference of the gradient seems to be mainly caused by the distance between strain gage on reinforcement and crack. In other words, the fairly agreement may be obtained on condition that the distance is zero. The distance is as follows; 29mm (16% of crack spacing) in No.1, 104mm (similarly 50%) in No.2 and 60mm (similarly 31%) in No.3.

For the purpose of evaluation of deterioration without observing of load, the increase of curvature under a constant strain of compression top fiber is used in this study. Figure 9 shows the diagram of curvature and compression strain at top fiber of specimen No.3 as an example. It is noticeable that the linear relation of compression strain and curvature exists for every cycle and the gradient becomes greater with cumulative cycle. Figure 10 shows the relation relative curvature and cyclic loading. The relative curvature is normalized with respect to the curvature of 1000 times cycle of 16.7kN, As a result, it is possible to evaluate the stiffness decline by the curvature for any constant compression strain.

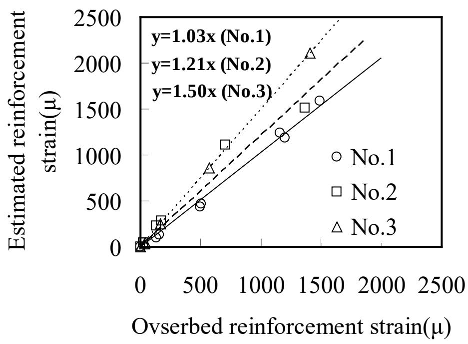


Figure8: Observation result vs. Estimation result

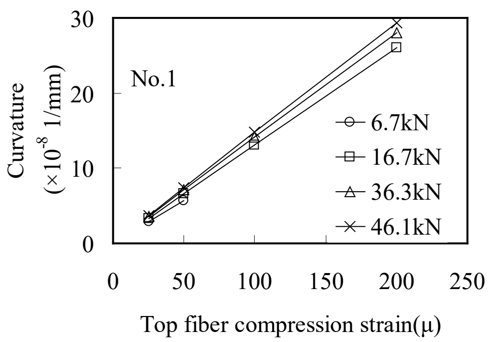


Figure9:Curvature vs. Top fiber Compression strain

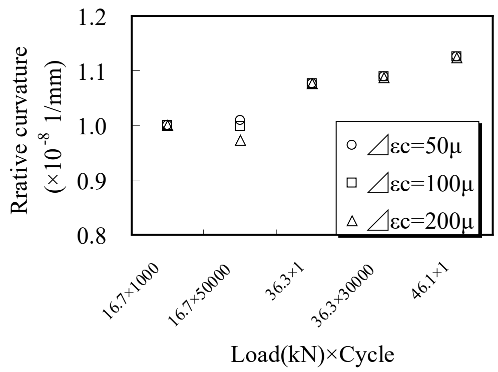


Figure10: Curvature vs. cyclic loading

3.2 Degradation of Fatigue Damage

In this study, growth of fatigue damage is evaluated on the basis of relation between maximum curvature and residual one as shown in figure 11. The maximum curvature is the sum of residual curvature and elastic one. The elastic curvature is the observation for a certain constant compression strain at top fiber (100 μ in this case) as mention in previous section. It is noticeable that the difference with the amount of reinforcement is small. Figure 12 shows the derivative of the residual curvature with respect to the maximum curvature (defined as "Rate of damage"). The damage rate gradually comes close to 1 with maximum curvature growth. That is to say, the growth of residual curvature seems to be distinguished with coming close to the yield of reinforcement.
Once more than two observations in situ will be obtained at an interval, it is possible to calculate increment of residual and of maximum respectively. Then the measurement rate of damage can be obtained by division the increment residual curvature by the increment maximum curvature. Comparing the measurement rate of damage with the previously calculated damage rate, the fatigue damage of structure can be evaluated quantitatively. And the damage rate is obtained by the ratio of residual and maximum curvature.

Residual is observation under no-loading.

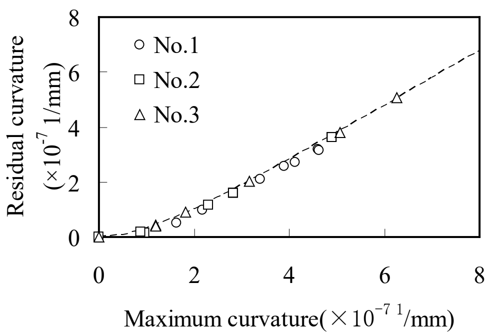


Figure11: Residual curvature vs. maximum curvature

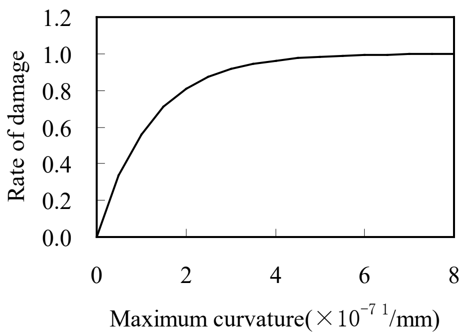


Figure12: Rate of damage

4. VERIFICATION

The results of static loading test of same bar arrangement specimens were adopted for verification of proposed method. The static tests were carried out to access the bearing capacity and determine cyclic loading way for each specimen in advance for fatigue tests.
For specimen No.1 as an example, the relation between the load and top fiber compression strain, and one between load and maximum crack width are shown in Figures 13 and 14 respectively. In the test, 6 times repetitive load with different maximum value was applied.
The relation between residual curvature and maximum one is shown in Figure 15.

And Figure 16 shows the relation of residual curvature increment and maximum curvature increment on the condition that the 3rd cycle is initial value. The relation seems to coincide with the results of fatigue tests, that is also illustrated together by dash line, on the condition that the residual curvature of 0.638 and maximum curvature of 1.50 is as initial values. That is to say, it is possible to evaluate fatigue damage progress using both increments of residual and maximum curvatures.

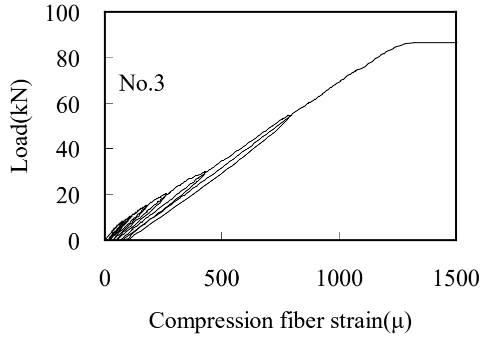


Figure13: Load vs. compression strain at top fiber in specimen No.1

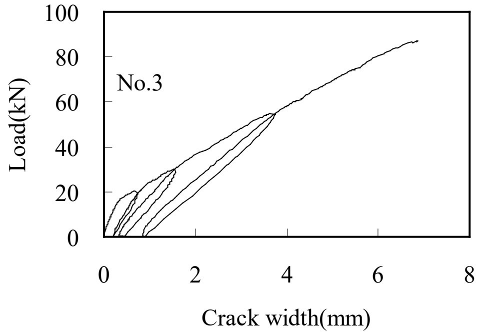


Figure14: Load vs. crack width in specimen No.1

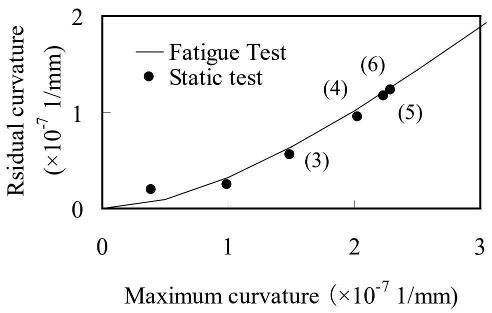


Figure15: Residual curvature vs. maximum curvature

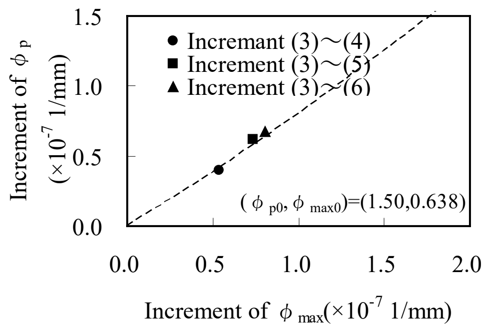


Figure16: Increment of ϕ_p vs. Increment of ϕ_{max}

4. CONCLUSION

In this paper, the quantitative evaluation method of fatigue damage by the use of the relation between increasing deformation and residual deformation caused by cyclic creep due to cumulative cyclic loading is proposed. The deformation is represented by the curvature obtained by the measured strain of extreme compressive fiber and reinforcing bar.

The following conclusions can be drawn:

a. The growth of fatigue damage is represented by the relation between maximum curvature and residual one. It is noticeable that the difference of the relation with the amount of reinforcement is small.
b. If more than two observations are carried out in situ at an interval, it is possible to calculate increment of residual and of maximum respectively. Comparing the measurement rate of damage with the previously calculated

damage rate, then, the fatigue damage of structure can be evaluated quantitatively.

c. As a consequence of the verification utilizing the static loading test, it is possible to evaluate fatigue damage progress using both increments of residual and maximum curvatures.

REFERENCES

Ministry of Laod, Infrastructure and Transport of Japan (MLIT), 2002. Annual statistics report of road, Japan Highway Users Conference.

Japan Society of Civil Engineers (JSCE), 2002. Standard specification for concrete structures "Structural performance verification", 14-16.

Meakawa,K., ISHIDA,T., and KISHI,T.(2009). Multi-scale Modeling of Structural Concrete, Taylor & francis.

The Time Change of Shape of Timber Bridge

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ABSTRACT

The timber bridge, "KINTAI-Kyo", is located in Iwakuni City, Yamaguchi Prefecture, JAPAN. It was built in 1673 and rebuilt several times until 2001 for washed away or its deterioration.
In 2001 "KINTAI-Kyo" was rebuilt as same shape in 1953. It is marked by the beauty of its five arches. The bridge length is 193m, every arch length is about 35m, its rise is about 5m and the wide is 5m. This bridge was made by some structural elements, KYOROKU(timber beam), KURA-GI(timber bracing), TASUKE-GI(timber parts), TAGA(iron hoop), KASUGAI(iron cramp), DABO(timber shear connector), etc.
After rebuilt in 2002, the shape of bridge, temperature and humidity are measured. The following results were provided by these measurements.
In the first year, the deformation at the center of bridge move 2cm downward for gaps between the structural elements. And there is a seasonal change of the deformation at the center of the bridge. At the center of bridge it moves upward in summer and downward in winter. The range of seasonal change is about 2cm. These changes are influences by temperature and humidity. In 2005 the irregular change of shape was observed in the autumn because no.1 bridge was washed away by the typhoon. These measurements have a possibility of safety diagnosis for timber bridge.

Keywords: *timber bridge, heritage, monitering*

1.INTRODUCTION

Figure 1 shows an elevation of "KINTAI-KYO" bridge. The bridge consists of five timber ones and is supported on each stone pillar. The bridge is 193.3m long and 5m wide. Three bridges of the middle part, from No.2 to No.4, are 35.1m long and the rise is about 5m.
It was constructed first in 1673 of Edo era by a feudal lord of the time, Hiroyoshi Kikkawa, to meet the transportation problems which the people faced every time when the Nishiki River flooded. The structural idea of the bridge is said to have come from a story of a Chinese priest of the Ming Dynasty who settled in Japan about the arch-type stone bridges of China.
Unfortunately, the entire bridge was washed away by a flood in May, 1674. But it was reconstructed in October, 1674. After that the bridges were often repaired and

reconstructed partially. Each bridge was repaired about every 12–15 years and reconstructed about every 20 years.

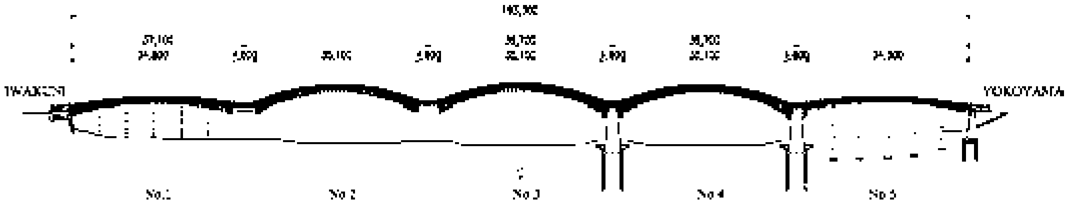


Figure 1: Elevation of “KINTAI-KYO” bridge [unit: mm]

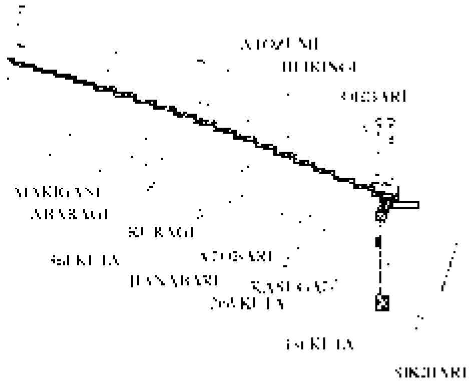



Photo 1: “KINTAI-KYO” bridge Figure 2: Detail of “KINTAI-KYO” bridge

The bridge we can see today was reconstructed from 2001 to 2004. This bridge is a replica of the original bridge reconstructed as the Edo design. Many Japanese traditional timber structures are preserved with maintenance, repairing and reconstruction. Even if they are rebuilt, the replica is re-built with original style and spilt of traditional timber technique. “KINTAI-KYO” bridge is composed of a lot of members. The main structure is KYOROKU (girder). The KYOROKU is composed of KETA (beam), KURAGI,TASUKEGI, HEIKINGI and ATODUME. They are connected with DABO (dowels), KASUGAI (cramps), nails and MAKIGANE (hoops), as shown in Figure 2.
There are past researches about the secular changes of “KINTAI-KYO”. The properties of vibration are measured and static loading tests were conducted by Waseda university[1]-[3] from 1953 with the interval of 5 years.
On the reconstruction of these bridges in 2002, investigation about deterioration was conducted. In these investigation two greatly deterioration were found. One is the decay of the bridges especially in the joint between the floor board and top of HEIKINGI as shown in photo 2. This decay of timber was caused by the puddles around the pegs. Other deterioration is the deformation of dowels between the beams as shown in photo 3. The horizontal deformations of the dowels were about 2-4 mm as shown in Photo 3.

Photo 2: The Decay of the top of "HEIKINGI" (Photo by Kamiyama.)

Photo 3: Deformation of dowel between beams

2. MEASUREMENT METHOD

The bridge shape and factors of secular change are being measured from 2003. In this year the no.4 and no.5 bridges were completed and just one year was passed from the no.3 bridge was completed. The no.2 and no.1 bridges were reconstructed in 2004 and there are the no.2 bridge passed about 50 years in 2001.

2.1 Shape

The shapes of the middle three bridges (no.2, no.3 and no.4) are being measured with theodolite. 13 targets were measured on every one side of bridge and 26 targets were measured on every bridge. Target points are the rivets bottom of the balustrades (Photo.4).
Measurements were started on March 14, 2003. In the first month the shape was measured with the interval of one week and in next two months it was measured with the interval of two weeks. After three month it was measured with the interval of one month and it was measured every 3 month from August 1, 2005.

2.2 Temperature and Humidity

Temperature and humidity influence the water content and the strain of wood. Especially wooden bridge is located in hard environment, above the river.

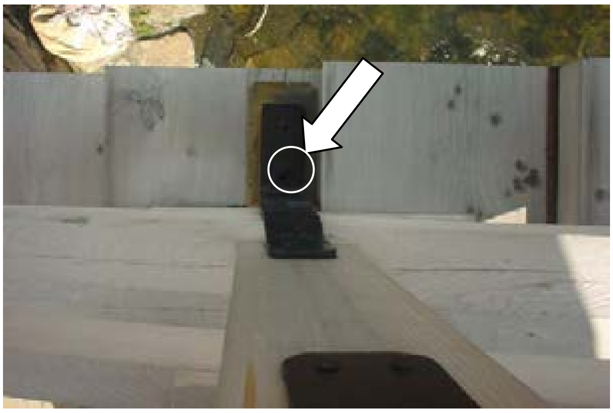


Photo 4: Target point of measurement

Photo 5: Thermo recorder

Temperature and humidity under the bridge are being measured with thermo recorder, T & D's TR72S, every one hour (Photo 5).

2.3 Live Load

For timber structure the creep deformation is one of the largest influences to the secular change. In case of this bridge the continuous or repeating loads and is dead load, its weight, and live load, crossing person. For estimating the live load, the number of sold tickets to cross the bridge was counted as the number of persons crossing bridge. Actually this load is underestimating because there are many not counting people with coupon tickets and group tickets.

3.RESULTS

3.1 Secular Change of the Bridge Shape

Figure 3 shows the deformation of the center of bridge. The horizontal axis shows how many days passed from the completion of each bridge. No.3 bridge is completed in 2002, no.4 bridge is from 2003 and no.2 bridge is from 2004. In the first year, from 0 to 365 days, the deformation of center of all bridges went down about 2 cm. But the deformation of no.2 was a little small. It is because this no.2 bridge has completed lastly and there is no construction after completion. After the first year they go up in summer and go down in winter. The width of change is

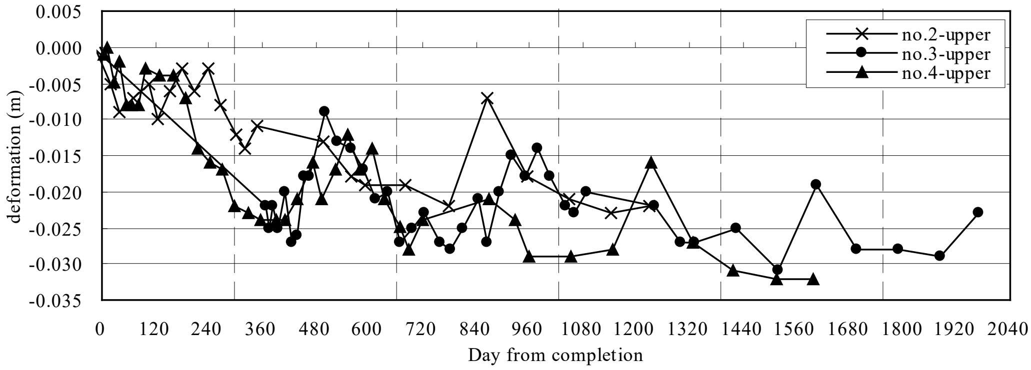
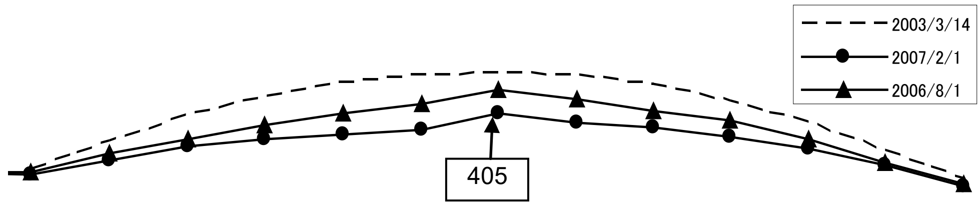


Figure 3: Deformation of the center of bridge (Upper part of a river)



The deformation is magnified by 50 times

Figure 4: The deformation of no.4 bridge (Upper part of a river)

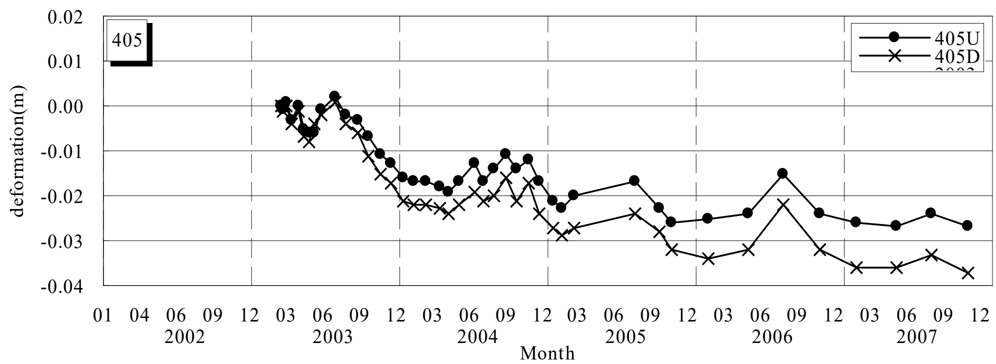


Figure 5: The deference between the upper part and the lower part of the river in bridge

about 1.5cm. The deformation of each point of no.4 bridge in the summer (Aug. 1, 2006) and in the winter (Feb. 1, 2007) are shown in Figure 4. The maximum deformation of bridge is at the point of a third part of bridge.

The deference of the deformation between at the upper part and lower part of the river in bridge is shown in Figure 5. This figure shows the deformation at the point 405 shown in Figure 4. The deformation at the upper part of the river in bridge is larger than at the lower part of the river and its difference grows larger. The deference is about 1cm in 500cm width.

3.2 Factors of Change

3.2.1 Temperature and humidity

Temperature and humidity were measured by thermo recorder every one hour. The results are shown in Figure 6 and Figure 7. Both temperature and humidity value are 7-day average before measuring the shape of bridges. The horizontal axis shows how many days from every January 1.

Temperature changes cyclically. The highest temperature, about 30 degrees Celsius, was recorded in August and the lowest temperature, about 5 degrees Celsius, was recorded in February. Considering the change of relative humidity, it is high because this bridge is located above the river. Especially it is over 90% in

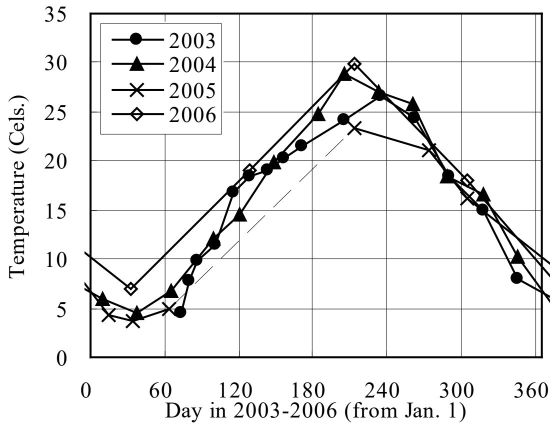


Figure 6: Change of temperature

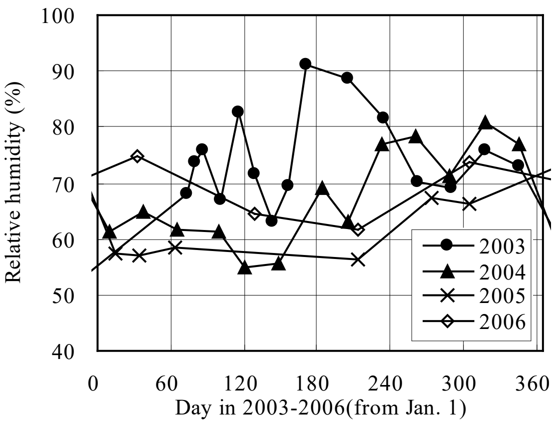


Figure 7: Change of relative humidity

every night and in every morning. But the change in the year is not cyclically and it is different from every year.

3.2.2 Live load

The number of sold tickets to cross the bridge was counted. This ticket is round-trip ticket, so the number of crossing the bridge is twice as this number. The number of sold tickets in month is shown in Figure 8. About 80-240 thousand persons cross the bridge every month. There are two peaks and over 100 thousand persons cross the bridge in April and November. In April they enjoy the cherry blossom on the bank of river and in November they enjoy autumn leaves. There is small peak in August and this reason is summer vacation. There are two off-peak in July and December. In June and July is the rainy season in Japan and in December it is cold in Iwakuni-city.

These numbers are reference value and maybe lower limit because there were the crossing persons who did not buy the tickets

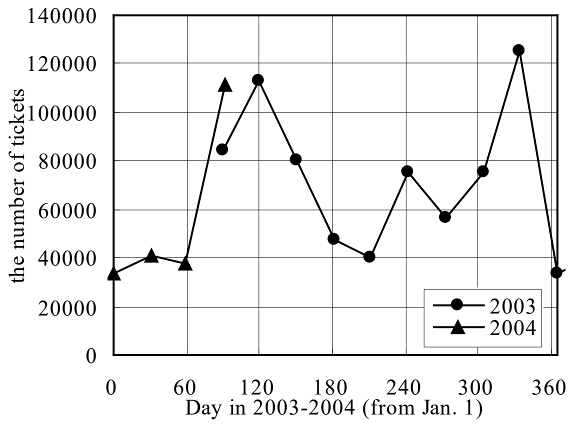


Figure 8: The number of persons crossing the bridge

3.2.3 Gap of connectors

"KINTAI-KYO" bridge is mainly composed of beams and these beams are connected to the other beam with dowels. These dowels are deformed by the shear force between beams. This deformation influences the shape of the bridges. By the field experiments in 2003[4]-[5] it is cleared that the vertical deformation of the center of bridge is 14.3mm if the gap between beams is 0.28mm and that deformation is 27.39mm if the gap is 0.67mm.

3.2.4 Typhoon

On September 6, 2005, the column of the no.1 bridge was washed away by a flood. The damage of no.1 bridge after typhoon no.14 is shown in Photo.5.


Photo 5: The damage of no.1 bridge after Typhoon

4. DISCUSSION

4.1 The Degree of the Influence to Secular Change

Timber bridge, "KINTAI-KYO" is changing its shape secularly and cyclically. Considering the cause of secular change of wooden bridge, there is many factor described in 3.2. In this chapter the degree of influence is considered.

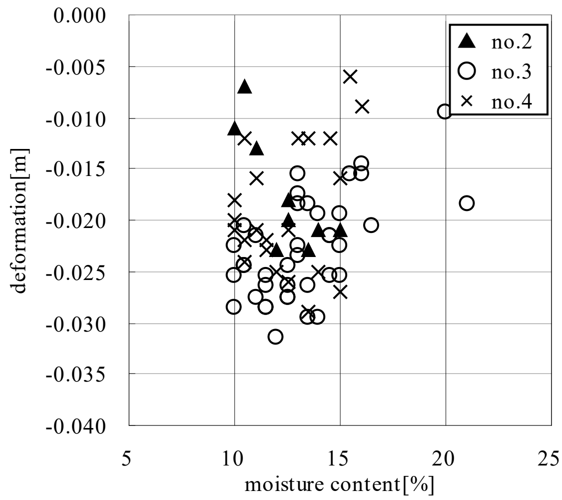


Figure 8: Relationship between moisture content and deformation

4.2 Temperature and Humidity

Temperature and humidity influence to the moisture contents of wooden members. Fig.8 shows the relation between the deformation of center of bridge and the moisture content. The moisture content of wooden member is calculated according to the theory of Hawley, Keywerth, Kollmann et.al.
In the no.3 and no.4 bridge the correlation between the deformation and moisture content, but in the no.2 bridge there is no correlation. In this figure the moisture content is changing from 10% to 15%. If the moisture content of wooden member is change from 10% to 15%, the change of length parallel to grain is about 0.15% and length perpendicular to grain is about 1.5%.

4.3 Typhoon

The no.1 bridge was washed away by a flood. The other bridge were damaged by washing away of no.1 bridge. The deformation of center of bridge was changed irregularly as shown Figure 9

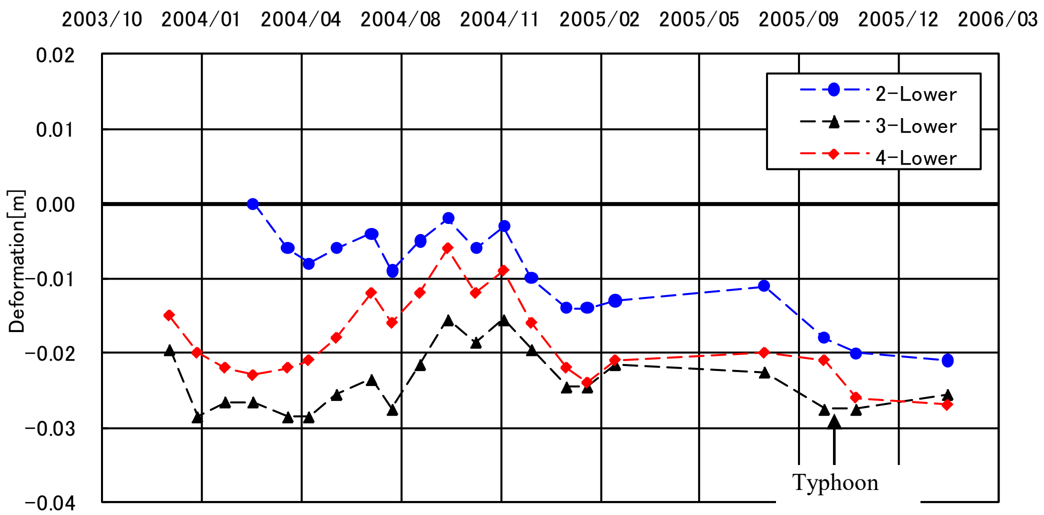


Figure 9: Change of deformation of the center of Bridge.

The no.4 bridge did not change as same as the no.2 and no.3 bridge. If these change can be monitoring, some damages can be found. These measurements have a possibility of safety diagnosis for timber bridge.

5. CONCLUSION

After rebuilt in 2002, the shape of bridge, temperature and humidity are measured. The following results were provided by these measurements.
In the first year, the deformation at the center of bridge move 2cm downward for gaps between the structural elements. And there is a seasonal change of the deformation at the center of the bridge. At the center of bridge it moves upward in summer and downward in winter. The range of seasonal change is about 2cm. These changes are influences by temperature and humidity. In 2005 the irregular change of shape was observed in the autumn because no.1 bridge was washed away by the typhoon. These measurements have a possibility of safety diagnosis for timber bridge.

ACKNOWLEDGEMENTS
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REFERENCES

[1]Takeshi SHINAGAWA: Report about reconstruction of “KINTAI-kyo”, Iwakuni-city, 1955
[2]Kusuo AOKI: Report about static and dynamic tests of “KINTAI-kyo”, 1953
[3]Research Center, Science Faculty, Waseda: Report about the Load Test of “KINTAI-kyo”,1998
[4]Mikio KOSHIHARA et al.: A study about “KINTAI-KYO” in Iwakuni Part 1-3, Summaries of technical papers of Annual Meeting Architectural Institute of Japan. C-1, pp.277-283, 2002
[5]Mikio KOSHIHARA et al.: A study about “KINTAI-KYO” in Iwakuni Part 4-6, Summaries of technical papers of Annual Meeting Architectural Institute of Japan. C-1, pp.469-474, 2003

Climate and Disaster Resilience of Asian Cities

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ABSTRACT

Over years, due to several human and natural factors, cities are becoming vulnerable to natural disasters. Climate change is imposing another additional threat, and due to different constraints of resources, it is important to focus on the city's resilience to reduce the disaster impacts. In an attempt to focus on enhancing resilience, Climate Disaster Resilience Index (CDRI) is developed to make a comparative analysis of the cities. The index is developed based on five vulnerability and resilience-based dimensions: natural, physical, social, economic and institutional. The scope of this study is limited to climate-induced disasters, such as cyclone, flood, heat wave, drought and heavy rainfall induced landslide. For each individual city case, resilience information is presented as overall resilience, and separate physical, social, economic and institutional resilience. Higher values of resilience are equivalent to higher preparedness to cope with climate and disasters and inversely. Based on the results, policy points and recommendations are suggested by the authors and provide encouragement of city governments' engagements in specific cist services, institution and capacity building. Not only are outputs from this study useful for city governments, but they also provide valuable knowledge and information to other local and national stakeholders having a similar target: the enhancement of community resilience. The CDRI is a considered as process to develop capacity of local governments to undertake decisive actions at city level.

Keywords: climate related hazards, resilience, urban risk, capacity building, Asia

1. INTRODUCTION

Urban areas, where 65 to 90 percent of economic activities of most Asian countries are concentrated, are experiencing ever increasing risk due to changing climate. On one hand cities are expected to continue acting as backbone of the nation's economy and on the other they also need to prepare to accommodate larger population because it is estimated that two out of three people on earth will live in urban areas by 2030. According to the United Nations Human Settlements Programme 2007, 'there is a constant pressure to keep pace with, if not lead, change in regional and global economic development. This, in turn, can be a force contributing to uncontrollable urban expansion and the generation of more vulnerability to disasters'. Moreover, since Asia is the most disaster-prone region, the incidences of climate-induced disasters are also high compared to other regions. Past disaster trends suggests that high density population in Asian cities increases the mortality and the number of affected people in a typical disaster event, which in turn also result in increasing economic losses in the region. There is a serious concern that the targets of Millennium Development Goals may not be effectively achieved if disaster risk reduction is not prioritized in development planning in general and urban development in particular.

With growing confidence of scientific community, climate change and induced impact on human life have become a burning issue not only for the environmentalists but also for the policy makers and world communities. Climate change is occurring, accompanied by significant changes in precipitation, temperature, and changes in the frequency and intensity of some extreme events. These changes will affect natural and human systems independently or in combination with other determinants to alter the productivity, diversity and functions of many ecosystems and livelihoods around the world. Yet these impacts will not be distributed or felt uniformly, as those "with the least resources have the least capacity to adapt and are the most vulnerable".

Settlement on marginal or unstable land such as coastal areas, mountainous areas, river basin and urban slums heightens their exposure to the impacts of climate hazards. With limited capacities and resources at their disposal to respond to stresses such as droughts, floods, typhoons and rainfall-induced landslides, their ability to meet basic needs and improve their lives is constrained. Climate change impacts and variability, therefore, threaten to exacerbate existing vulnerabilities and further entrench development disparities. Therefore, there is a need to build a resilient community that would be efficiently capable to face climate change and associated disaster risk. For that, city governments need to be aware of current and future potential risk and take more initiative in order to enhance the resilience of the urban systems and communities.

Despite growing recognition of 'building resilient communities and enhancing adaptation to climate change', Asian urban communities are not yet receiving adequate attention. Most of the explosive growth is going on in developing countries of Asia where already about half of the urban population live in slum areas. These large proportions of the people are also at higher risk from the effects of climate change. Many urban dwellers have already started to face life-threatening risks from the increased intensity of storms, flooding and landslides that climate change is bringing. These and other impacts will also bring the threat of damage to their livelihoods, property, environmental quality and future prosperity. *[References: United Nations Human Settlements Programme, 2007; IPCC, 2001; IISD, SEI, IUCN, Intercooperation, 2003; ID21, 2008; DFID, 2007; IDS, 2007; UNHSP, 2003]*

2. METHODOLOGY

This study recognizes that the scale of developmental concerns Asian cities are expected to address in a very near future will be behemoth. Moreover, even the best possible and technologically advanced resource provisions cannot ensure elimination of threats which is already demonstrated through experience of hurricane Katrina. Therefore, more attention needs to be paid to raise the resilience of both urban local organizations and communities to climate change and associated disasters. This study looks at different dimensions of resilience from the lens of urban communities. Understanding urban problems and recognizing potentials within communities is of utmost importance to enhance resilient to climate change risk and disasters. It attempts to measure the existing level of climate disaster resilience of urban communities. The scope of this study is limited to climate-induced disasters (hydro-meteorological disasters), such as cyclone, flood, heat wave, drought and heavy rainfall induced landslide and building resilience against them.

In the attempt of building a resilient community, key questions that need to be answered are:

- How to enhance resilience of the community?
- What are the indicators that need to be addressed to be able to characterize and measure Climate Disaster Resilience?
- How can we create an effective index to assess the level of climate disaster resilience of a vulnerable urban community?

This research is an attempt to seek answers to these queries by focusing on the urban communities of Asian cities. It aims to enhance community resilience after evaluating the existing level of climate disaster resilience of a community using a Climate Disaster Resilience Index (CDRI).
In this initiative, community resilience can be understood as:

- Capacity to absorb stress or destructive forces through resistance or adaptation
- Capacity to manage or maintain certain basic functions and structures during disastrous events
- Capacity to recover or 'bounce back' after an event.

This concept comprises the capacity of a community to absorb stress (hydro-meteorological disasters), to manage it and to recover from it. It is assumed that if a community can raise its climate resilience, it would enhance its disaster resilience and finally these two resiliencies would enhance community's resilience to climate disaster risk.

3. RESULTS AND DISCUSSION

The community's climate disaster resilience would be assessed considering the following dimensions:

- Natural: topography, disasters, natural environment degradation, hydro-

meteorological situation
- Physical: history, location, accessibility, infrastructure and utilities, housing condition, land tenure, environmental degradation,
- Social: population, health, education, knowledge and awareness, social capital, conflict, crime,
- Economic: income, employment, expenditures, assets, access to financial services, financial coping mechanism
- Institutional: internal and external institutions, institutional collaboration, coordination and cohesion

Figure 1. Five dimensions of CDRI

Based on these dimensions, a methodological approach is developed to determine a Climate Disaster Resilience Index (CDRI).

Briefly, outcomes of this study are:
- Methodology of CDRI development;
- CDRI to measure community's climate disaster resilience;
- Climate Disaster Resilience Map for the identified communities;
- Strength and weakness of different sectors of each dimension of CDRI (physical/social/economic/institution authorities and development organizations can prioritize the sectors for policy implication.
- Inputs for policy formulation process of development organizations for urban communities risk reduction.

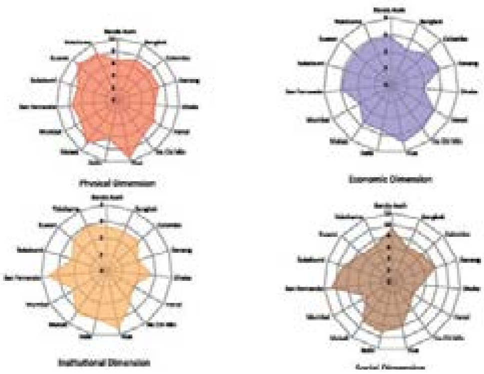

Figure 2. Results of CDRI

Climate and Disaster Resilience Index (CDRI) and the analysis are based on the questionnaire survey, filled up by the city officials. The quality of results is very much dependent on the data quality, and proper understanding of the questionnaires. Needless to say, these results are not absolute values, but broad policy guidance and scope of improvements in selected sectors of the climate and disaster related problems in the respective cities.

On the overall analysis, there are six graphs showing comparative nature of cities. This comparison is made to highlight the positive side of city's preparedness. One graph shows overall city's resilience, and five other graphs demonstrate city's resilience in terms of natural, physical, social, economic and institutional.

For each city, five graphs are presented: overall resilience (combination of all five factors), and physical, social, economic and institutional resilience. Higher the value of the resilience means higher preparedness to cope with climate and disasters. Policy points are based on the results, and provide encouragement of city government's engagements in specific city services and institution and capacity building.

REFERENCES (including non-cited reference)

ADB, Managing Asian Cities: Sustainable and Inclusive Urban Solutions. (Asian Development Bank, 2008)

The World Bank, World Development Report 2009. (The World Bank, 2008). Retrieved January 21, 2009 from http://www.worldbank.icebox.ingenta.com/content/wb/bk17607/

IDS, Building Climate Change Resilient Cities, IDS in Focus Issue 02.6 (2007). Available at www.ids.ac.uk

UN-Habitat, Global Report on Human Settlements 2007, Enhancing Urban Safety and Security, United Nations Human Settlements Programme (UN-Habitat), (Earthscan, London, 2007).

J. T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden, and D. Xiaosu (eds.), Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press: 944, (Cambridge, 2001).

IISD, IUCN, SEI-B, Intercooperation [International Institute for Sustainable Development, IUCN–The World Conservation Union, Stockholm Environment Institute–Boston Center], Livelihoods and Climate Change: Combining Disaster Risk Reduction, Natural Resource Management and Climate Change Adaptation in a New Approach to the Reduction of Vulnerability and Poverty. (Winnipeg, Canada IISD, 2003). Also available at www.iisd.org/pdf/2003/natres_livelihoods_cc.pdf.

ADPC (Asian Disaster Preparedness Center), Building Disaster Risk Reduction in Asia- A Way Forward ADPC Looks Ahead to 2015. (Bangkok Thailand, 2004). www.adpc.net

A. Kreimer, M. Arnold and A. Carlin (eds.), Building Safer Cities: the Future of Disaster Risk, Disaster Risk Management Series, 299pp (The World Bank, Washington USA, 2003).

J. Twigg, Characteristics of a Disaster-Resilient Community; a Guidance Note, version 1 for field testing, for the DFID Disaster Risk Reduction Interagency Coordination Group (Benfield UCL Hazard Research Centre, 2007).

S. Huq, A. Rahman, M. Konate, Y. Sokona and H. Reid, Mainstreaming Adaptation to Climate Change in the Least Developed Countries. IIED (London, 2003).

IPCC, Impacts, Adaptation & Vulnerability, IPCC Working Group-II, IPCC 4th Assessment Report, (IPCC, 2007). Available at http://www/gtp89.dial.pipex.com/10.pdf

L. Briguglio, The Vulnerability index and Small Island Developing States. A Review of conceptual and methodologies issues. (University of Malta, 2003).

G. McGranahan, D. Balk and B. Anderson, Environment and Urbanization 19, 1, 7 (2007)

IPCC, Workshop on the Detection and Attribution of the Effects of Climate Change. Working Group II Workshop Report. GISS (New York. USA, 2003)

The Community-based Planning and Consideration of Countermeasures through Workshop in "Below-Sea-Level City" against Forthcoming Flood Disasters
– Case in Katsushika City in Tokyo -

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ABSTRACT

There are high-density and broad urban areas below the sea level, we call "BELLOW-SEA-LEVEL CITIES (BSLCs)". There are few safe facilities or area for evacuation in case of flood disaster, therefore, huge amount of residents more than two million in Tokyo have high exposure risk. Huge physical and human damage is estimated in case of a wide-scale flood. Meanwhile, sea level rising and emergence of huge typhoons is estimated in the future according to IPCC (2007). Some sort of countermeasure from the aspect of urban planning and architecture is needed in below-sea-level city in preparation for gradual flood disaster risk rising. We have tried to study countermeasure with NPO and community association in Katsushika City in Tokyo since 2006. In this paper, we report a series of resident collaborative workshop.

Keywords: *climate change, urban planning, community-based planning, residents collaborative planning*

1. INTRODUCTION

According to Ministry of Land, Infrastructure, Transport and Tourism (MLIT) 2005, a population living in areas under the sea level is said to be a total of more than four million in three major metropolitan areas in Japan, i.e. Tokyo, Osaka and Nagoya metropolitan areas. We call these areas "BELLOW-SEA-LEVEL CITIES (BSLCs)". BLSCs have been exposed to flood risk and the risk has been increasing corresponding to climate change. However, recently, few floods have occurred in BSLCs because of the enhancement of flood-control. As a result, the awareness of flood risk has been declining and the preparation for flood cannot be enough.

These areas also have another risk to not usual flood but one following an earthquake. The probability of the conjunction of an earthquake and an extreme weather causing flood may be negligible; however, the probability of the occurrence of an extreme weather under repairs of damaged flood-control facilities including banks will not be negligible because they have possibility to be damaged by a huge earthquake and the recovery will need much time. If damaged bank was broken, wide spread built-up would be under water for a long time.

Revision of flood prevention law in 2005 has obligated municipalities to publish a flood hazard map which has information of flood hazard and evacuation areas. However, municipalities in BSLCs have difficulty to make an understandable hazard map for citizens because they have no safe evacuation areas in case of flood. For example, Katsushika city located in BSLC of Tokyo had no choice but to induce more than 27 million people to evacuate for terraces on a hillside more than 10km far away with no exposure to flood. For comparison, evacuation areas against post-earthquake urban fire spreading are allocated to be less than 2 km for all citizens. The evacuation will be difficult under the present condition in case of wide scale flood.

At the present time, there is no perfect solution for BSLCs, therefore, consideration of countermeasures and various kinds of planning including mitigation and evacuation will be essential.

This paper reports a case of community-based planning and consideration of countermeasures against mega flood disasters. It is residents collaboration through workshops schemed by experts group and a non-profit organization (NPO) in Katsushika City which is typical BSLC in the east of Tokyo. A total of seven workshops and 4 events have been implemented by collaboration from FY2006 until the present. In a series of the activities, there are several experiments or ingenuities in this paper, we focus on them and discuss to share common problem and our experience with readers.

2. OUTLINE OF CASE STUDY AREA

2.1 A Study Area

Our study area is located in the east of Tokyo and named North Shin-Koiwa district. It is enclosed by three rivers: the Arakawa, the Shin-Nakagawa, and the Nakagawa, on three sides (See Figure 1). The district has an area of approximately178 ha and has a population of 32,000 in 2004. It had been built up with low-rise buildings.

This district has not experienced since flood disaster in 1947. The residents had little interest in flood disaster.

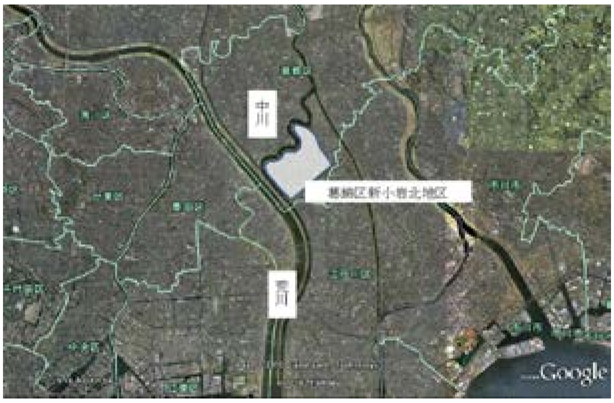
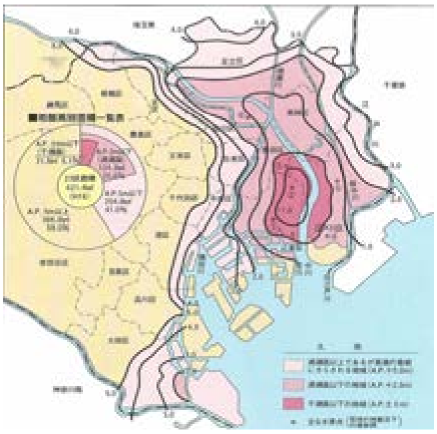


Figure 1 Study Area (northern Shin-Koiwa District in Tokyo)

2.2 What Create BSLCs?

BSLCs were rural zone above sea-level before modernization. They have been created by artificially. A large amount of ground water pumping through industrialization caused subsidence in vast area of river plain. The Subsidence had continued for approximately eighty years until regulations for ground water pumping placed in 1970'. On the other hand, urbanization had expanded into these areas rapidly since 1960' although the subsidence was apparent. In fact, BSLCs had been born by two failures: the overdue regulations and urban planning without a concept of risk management. At present, a population of approximately two million lives in BSLCs (See Figure 2)



Area exposed to tidal flood risk: 254.6km2
Area under high tide sea level: 124.3km2
Area under low tide sea level: 31.5km2

Figure 2 BLSCs in Tokyo (Tokyo Metropolitan Government)

3. COLLABOLATIVE ACTIVITIES IN BSLCs

3.1 Implementation Organizations

Concerned parties of the activities are three: NPO which have the base in the district and act for creation of safe and amenity city, experts group who has various kinds of specialties: urban planning, river engineering, municipal administration and disaster prevention, and a community association which is called "CHOKAI". Each party has different roles. The original sharing role is as follows: NPO and experts group play a role as project managers. NPO is total coordinator, and experts group give various kinds of know-how needed. The community association is participants of workshops. As mention later, the role sharing has been changing by gradation.

Figure 3 Collaboration of three different kinds of organizations

3.2 Outline of Workshops for Planning and Consideration of Countermeasures

The activities started from FY2006 and have succeeded up to present date. A total of seven workshops and four events schemed by experts and NPO were implemented and they have induced community association to take their countermeasures by themselves. Administrative officers of the municipality have participated in them as observers and supported from backward.

The activities can be classified into four stages. The stages cover from risk communication to implementation of countermeasure. Especially, they were designed to consider both short-term countermeasures such as evacuation planning and long-term ones such as urban planning including creation of high land for evacuation.

The first stage had been implemented in FY2006. The objective was to understand risk and consider a scheme of countermeasures they should take. We have two intents. The first is to promote discussion based on facts. We used not only usual tools such as map exercise and field work, but outputs of analysis with GIS including flood simulation. The participants confirmed that their houses were sinking, and could understand flood risk as their own. The second is to the balance of short-term and long-term countermeasures. When people first realize risk, they naturally weigh on short-term countermeasures in order to remove risk at hand rapidly. As result, long-term countermeasures including drawing a vision of town tend to be forgotten. In the program, we focused on the scheme and avoid detail discussion of each countermeasure. The balance has continued to be kept up to the present date thanks to enough discussion of the scheme at that time.

The second had been implemented. The aim was to consider countermeasures we can do. Two main issues were raised. They were evacuation plan as short-term countermeasures and drawing a vision of their town as long-term ones. They understood the difficulty to evacuate and intended to look for solutions. Especially they discuss practicable solution focusing on those who require support such as elderly persons and disable persons. As for long-term countermeasure, they who don't have sense of urban planning are difficult to draw a vision; therefore, we prepared a planning tool to inspire imagination. We use an amount of LEGO blocks corresponding to an area of evacuation which residents need and put them on a map of their town. It facilitated building-up and sharing of spatial image among the participants. They could two alternatives, creation of high-rise land in riverside or public facilities such as elementary schools. They shared the direction in the future.

The third stage is implementation phase. Independent implementation by community had started in practical. They hold a workshop for risk communication, which corresponds to the first workshop they had experienced, by themselves. The most important problem at that time was that problems of a community were shared among only the participants. Propagation for other residents who are not participants was a hot issue. The best way to do so was that the participants taught non-participants. They had trained the operation of GIS before the workshop and they operated GIS in front of the residents in a workshop. For reference, they were more than sixty five years old, and have no skill at all. We can say that they had much high motivation. The others were two drills: ones of long distance evacuation and of preparation of meals outdoors as refugees. The role of NPO and experts has been changing from as project manager to as supporter.

The newest stage has just started from FY2010. It has focused on a new theme, long-term measures of making safe evacuation area in neighborhood and considered realization procedures with a view to revision of the existing institution of redevelopment. NPO, community, experts and administrative officers has collaborated.

In addition, there were two events and two symposium held. Two events were intended to lead the change in thinking. Motivation of the participants might decline because they cannot get a kind of fun in front of mega-risk. We think that a kind of fun is essential to keep motivation and continue activities. On the other, two symposiums were prepared as one of solution for a problem. Of course, neighbor communities had same problem, and should share the problem consciousness. We regarded a symposium as place to appeal for neighbor communities. They invited leaders of neighbor community associations and adopted each declaration in a symposium involving them.

Table 1 Outline of Collaborative Action

1st Stage: Consider countermeasure by yourselves. (FY2006)	
1st Workshop	Understand problems as your own.
2nd Workshop	Confirm the structure of preparation for flood and clarify what a community and an individual should consider.
3rd Workshop	Consider the preparation which a community and an individual should implement.
1st Event	Board a boat :Boat handling training through boating in the sea
2nd Stage: Start short-term countermeasures and consider long-term ones in detail (FY2006-2007)	
4th Workshop	Understand a hazard map with more realism
5th Workshop	Draw up the vision of town in the future
2nd Event	Observe our town from the river on a ship
1st Symposium	***Draw up the declaration of preparation for flood and climate change as a town.***
3rd Stage: Induce participants to implement self-motivated actions (FY2007-present)	
6th Workshop	Organize workshop of the community, by the community, for the community
7th Workshop	Select countermeasures which should be implement
Self-motivated Action of town resident association (FY2009 -)	
1st Action	Implement drills of long distance evacuation
2nd Action	Implement drills of preparation of meals outdoors as refugees
to be continued	
2nd Symposium	***Draw up the declaration of implementation of countermeasure and climate change as a town.***

4. CONCLUSION

The community-based planning and consideration of countermeasure for mega-flood disaster will be new approach in Japan. Previously, the river administration had entirely charge of flood control. Approach from urban planning or community didn't exist as a concept. However, it will be essential for mega-flood taking climate change into consideration. This case can become the first case. In what follows, we consider achievement and assignment.

4.1 Achievement of a Series of Activities

We can say that this case is best practice. The fact that community own activities have been implemented naturally demonstrates it. We get standardization of method for planning and consideration of countermeasures for mega-flood disaster in BSLCs through a series of activities. In this regard, we need to point out that the ability of facilitators determines the feasibility of workshop. Further standardization will be needed.

At the same time, it was demonstrated that the structure of organizations constituted with NPO, experts and community is effective. In this case, administrative officers had stood backward as supporters. If they were members of project managers, the residents would claim many countermeasures of which the public sector takes the initiative and independent activities of community would not be induced. On the other, administrative officers generally prepare kinds of countermeasures when they show the citizens the risk information. The structure of this case will be one of models of new public sector.

4.2 Next Challenges

There are many challenges left. People in the community who share common understanding with the participants remain minority. Further propagation inside the community will be needed. At the same time, neighbor communities share a common destiny. They need to advance their activities for collaboration with neighbor communities. At present, the community is projecting workshop with junior high school students which the participants have charge of facilitation. NPO and the community implement traveling exhibition on mega-flood risk in Katsushika city this year.

REFERENCES

Tokyo Metropolitan Governments: height of low land in Tokyo, Japan.
Ministry of Land, Infrastructure, Transport and Tourism, 2005.10, The present situation of lowland area under sea-level, Japan
T.Kato, K.Ishikawa, and T.Ichiko, 2007.5, The Community-based Workshop to Correct the Awareness of a Flood Damage and Discuss Measures, Proceedings of Infrastructure Planning Japan
T.Kato, K.Ishikawa, and T.Ichiko, 2008.5, The Community-based Workshop to Understand the Hazard Map and Discuss Long-Term Measures, Proceedings of Infrastructure Planning Japan

Climate-Resilient Development in Urban Areas – A Perspective from Malaysia

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ABSTRACT

Climate change mitigation and adaptation are generally played out in different policy domains involving different stakeholders. Mitigation is driven primarily by agreements at the UNFCCC, which would require national responses. Adaptation issues tend to be confined to affected entities at national, state, local and community levels. In an effort to reconcile these differences, the Malaysian Government has defined climate-resilient development as "development that takes into account measures to address climate change and extreme weather in line with national priorities". Spatial planning responses provide an opportunity for adaptation-mitigation interactions. However, in the immediate term, the priority should be on adaptation to minimize the impacts of climate change to reduce the risk of disasters. For this purpose, the ongoing terrain assessment approach has to be expanded to include potential interaction with climate related stressors. The priority should be to identify highly susceptible urban areas and delineate socio-economic dimensions such as exposure, coping capacities and adaptive capacity.

Keywords: climate change, adaptation, hazards, vulnerability, spatial planning

1. INTRODUCTION

In order to achieve sustainable urban development, it is necessary to ensure that the planning process includes socio-economic considerations, management of resources and suitability of land, taking into account potential hazards and environmental impacts. In addition, the planning process also has to take into account the changing climate and its potential impacts so as to reduce vulnerability and ensure resilience of any proposed socio-economic development project. It would be more cost-effective to take adaptation measures early on, especially for critical infrastructure with long economic life.

Changes in climate may be due to natural processes or to persistent anthropogenic changes in atmosphere or in land use. The definition of climate change as used in the United Nations Framework Convention on Climate Change (UNFCCC) includes only those changes that are attributable directly or indirectly to human activity. There are two central actions associated with climate change, mitigation and adaptation. Mitigation refers to actions taken to reduce greenhouse gas (GHG) emissions and enhance sinks to tackle the causes of climate change. Adaptation refers to actions taken to help communities and ecosystems cope with actual or expected impacts of climate change (IPCC, 2007).

This paper commences with a brief articulation of resilience as perceived in the climate change and disaster risk reduction platforms, and its relationship to climate-resilient development. The potential for both climate change adaptation and mitigation within the spatial planning processes is briefly alluded to in this section. The subsequent focus of the paper is on climate change adaptation. This is in light of the immediate intervention that is required to reduce vulnerability and build resilience in a changing climate. Knowledge on hazards and vulnerability is highlighted. This is followed by a brief discussion on circumstances in Malaysia, and the means of addressing them. The main aim is to accentuate the possibility of expanding existing assessments to incorporate elements to address climate change adaptation within the spatial planning processes in Malaysia.

1.1 Climate-Resilient Development

Resilience in the context of the climate change discourse refers to "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change" (IPCC, 2007). Resilience in the context of the disaster reduction community refers to "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure" (UNISDR, 2005). The ability of the social system to learn from past disasters would influence its capability to be better prepared to respond to future disasters.

The IPCC definition of resilience is generic in that it does not qualify the nature of the "disturbance". However, in the UNISDR definition, the nature of the "disturbance" is specified in the form of exposure to hazards. Furthermore, there is emphasis on retaining "the same basic structure and ways of functioning" in the former as distinct from "to an acceptable level of functioning and structure". The difference in the definitions from both these institutions is open to interpretation. In the context of the climate change discourse, it could be interpreted that resilience alludes to both climate change mitigation and adaptation. In the context of the disaster risk reduction, the emphasis is only on climate change adaptation.

This is particularly pertinent with respect to the term "climate-resilient development". Generally, the term is widely used and tends to be associated with adaptation and the need to ensure that a social system has the capacity for self-organisation and ability to cope with the change. This inference is most likely derived from the definition of resilience associated with the disaster risk reduction community, which clearly confines the term "disturbances" to exposure to hazards. However, "disturbances" could constitute more than threats posed by the physical manifestations of climate change such as sea-level rise, floods, etc. Disturbance could also be interpreted as social and economic pressures to curtail GHG emissions. Such pressures would require reallocation of development funds for mitigation measures that may undermine socio-economic growth and distribution efforts, particularly for developing countries.

Climate change mitigation and adaptation are generally played out in different policy domains involving different stakeholders (Tompkins and Adger, 2005). Mitigation is driven primarily by agreements at the UNFCCC, which would require national responses. Adaptation issues tend to be confined to affected entities at national, state, local and community levels. In an effort to reconcile these differences, the Malaysian Government has defined climate-resilient development as "development that takes into account measures to address climate change and extreme weather in line with national priorities" (Government of Malaysia, 2009). Issues associated with mitigation tend to have an explicit economic orientation involving business and industry. Examples include carbon offset schemes, financing and transfer of technologies related to energy efficiency and renewable energy to promote GHG emission reduction and Reducing Emission from Deforestation and Forest Degradation (REDD) to promote sink enhancement. Adaptation issues are tend to be related to resource security with respect to its depletion and community safety in relation to hazards and disasters.

The implication of the National Policy is manifold in several levels. Key actions have been formulated to balance adaptation and mitigation in the quest for climate-resilient development. Climate change responses to-date has been implemented in a disjointed manner with emphasis on mitigation and mainly in the federal government level. Actions to balance adaptation and mitigation will now have to be implemented at all levels. This will be a very challenging task at the state and local levels because land, forests, water and other resources come under the purview of the state government. State governments and local authorities are generally constrained by limited knowledge, capacity and resources. Urban areas under the management of local authorities pose the biggest challenge as many are unaware of not only climate change issue, but also of existing hazards that may undermine development in the near term.

There is much potential for both adaptation and mitigation through the spatial planning process. Urban landuse planning at the local authority level results in structure plans and local plans, which takes into account several aspects. These include economic needs, population density, existing land use and other factors associated with the development process as well as environmental aspects such as conservation of wetlands and catchment areas. Conservation efforts will contribute to natural carbon sequestration and this would constitute as a mitigation measure. Initiatives for assessing such potentials are expected to commence shortly, with implementation of the National Policy on Climate Change, which advocates balanced adaptation and mitigation. However, the immediate focus should be on climate change adaptation as climate change is very likely during the 21st century (IPCC, 2007). The projected change and increase of hydrometeorological hazards is also likely to have consequences on certain geological hazards (NAHRIM, 2006). Immediate intervention is required to reduce vulnerability and build resilience in a changing climate.

1.2 Hazards and Vulnerability

Hazards are potentially disruptive physical events, substance, phenomena or human activities that may cause the loss of life or injury, property damage, social and economic difficulty or environmental degradation, including dormant conditions that may represent future threats (UNISDR, 2004). Disasters are consequences of such disruptive events, phenomena or human activities on human life, properties and infrastructure within a specific geographic area in a given period of time. Hazards have always played an important role in shaping social and cultural development. They threaten humans and their properties and infrastructure; and without any form of intervention, hazards always lead to disasters. Catastrophes are very severe disasters where almost all members of a community and their basic supply centers are disrupted and they cannot help each other; making delivery of humanitarian aid difficult if not impossible.

Vulnerability refers to the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UNISDR, 2004). Climate change is expected to contribute to increasing the occurrence of natural disasters in the future (Cruz et al., 2007). In the context of climate change, vulnerability is the degree to which a system is susceptible to and unable to cope with the adverse effects of changes, in term of the character, magnitude and rate of change, as well as the exposure, sensitivity and adaptive capacity of the system (IPCC, 2007). Adaptive capacity in relation to climate change impacts refers to the ability of a system to adjust to changes in climate to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Risk is generally viewed as the function of hazard levels and vulnerability of the elements exposed. Over the years, the concept of vulnerability has been made more comprehensive to include susceptibility, exposure, coping capacity and adaptive capacity, as well as different thematic areas, such as physical, social, economic, environmental and institutional vulnerability (Birkmann, 2007). The implication of the expansion of the definition of vulnerability is that the usage of “risk” becomes less useful in the context of hazards influenced by climate change for a given area, with respect to the long-term changes associated with climate change. It would be meaningful to assess risk for observed changes and current drivers of change for a system in present conditions, and more so if it is related to a social decision (Tompkins and Adger, 2005). Any assessment of long-term risks would entail a projection of future changes in physical conditions framed around scenarios of social, economic, environmental and institutional set-ups, resulting in high levels of uncertainty. A vulnerability assessment is more useful in this context, to come to a social decision.

Vulnerability assessments encompass current characteristics of a hazard and its interaction with climate related stressors (susceptibility components), representing the intrinsic weakness of a system, as well as socio-economic dimensions such as exposure, coping capacities and adaptive capacity. This is particularly relevant to a developing country, which would have the opportunity for making spatial planning responses as a form of policy intervention, in the present time to avoid future exposure. It is also relevant for strengthening coping capacities and adaptive capacity. There are also economic advantages in this approach, as the costs of remediation or application of adaptation technologies would be reduced. In addition, the need for adaptation technologies could be identified more effectively.

2. CURRENT CIRCUMSTANCES

In Malaysia, the most common hydrometeorological disaster is flooding. The phenomenon has affected the greatest number of people over the last century (Liew, 2009). Urban areas are particularly affected by flash-floods. Between 1990 and 1996, over 100 incidents were reported in the Klang Valley alone, where Kuala Lumpur is located (Pereira & Komoo, 2004). Flash-floods usually occur with little or no warning after heavy rain and can reach peak level in a short time. A number of reasons contribute to flash-floods in urban areas. These include increased impermeability due to an increase in the built-up areas and increased accelerated erosion from exposed surfaces resulting in sedimentation of rivers and streams, which subsequently cause flash-flood along flat low-lying river channels. Flash-floods in urban areas are also due to poor maintenance of drainage facilities (Jamaluddin, 1986).

Reports of disasters related to rock-falls and subsidence have been reported in the City of Ipoh, coinciding with urban expansion into limestone terrain. Around Kuala Lumpur and Penang, the onset of economic growth and expansion of the city into hilly terrain have resulted in landslides and slope failures becoming more prevalent. Such disasters have taken its toll on the urban population. Between 1990 and 1996, about 20 incidents were reported around Kuala Lumpur alone, with total fatalities amounting to 48 people (Pereira & Komoo, 2004).

Engineering approaches are the most common way to address hazards in urban areas. There are many flood mitigation projects to address the flash-flood situation, particularly around Kuala Lumpur. Such projects have served to lessen flash flood disasters in limited parts of the city. Engineering solutions are also commonly prescribed to remediate landslides and slope failures. In one particular case, apartment blocks had to be abandoned after the structure was found to be unstable, causing much hardship to its residents.

In an effort to move away from remediation to prevention, the Minerals and Geoscience Department of Malaysia embarked on a systematic large-scale urban mapping exercise. The geological terrain assessment involved systematic segmentation of an area based on landform patterns, geology, drainage and surficial processes (Chow& Ferdaus, 2000; JMG 2006). The GIS-based assessment used a combination of information from remote sensing and field mapping. A series of thematic maps on physical constrains, erosion and instability were produced, to provide information on susceptibility of an area to floods, landslides and subsidence. The end-product of the assessment is a construction suitability map, to support planners and decision-makers in development of urban areas.

The Town and Country Planning (Amendment) Act 1995 (Act A933) exerts primary control over the planning process in Malaysia. The Act has two components and these are land use planning and development control. Local authorities are empowered by this Act to incorporate elements of safety, health and well-being as part of the development control process (Ismail, 1996). In some states, local authorities have used information from terrain assessments to evaluate the suitability of a proposed development projects on a routine basis. However, this practice is limited to very few local authorities. The majority of local authorities have yet to apply this practice.

Efforts have been made to help planners and decision-makers to understand and appreciate terrain assessment and disaster reduction due to geological hazards. This includes creating effective linkages between geologists, planners and decision-makers to increase the awareness of the essential contribution of terrain assessments to sound planning. Notwithstanding this, much more needs to be done, especially to address the new challenges that are anticipated in the onset of climate change.

3. ADDRESSING FUTURE CIRCUMSTANCES

In Malaysia, localised climate projection indicate a substantial increase in monthly rainfall over the North East Coastal region and decrease in monthly rainfall in West Coast of Peninsular Malaysia may be expected by 2050 (NAHRIM, 2006). By end of the century, a more significant change in the annual rainfall may be expected in the western regions of Sabah and Sarawak (Wan Azli et al., 2008). Simulations of future river flows in several watersheds in the east coast of Peninsular Malaysia indicate increases in hydrologic extremes, i.e. higher high flows and lower low flows when compared with historical levels (NAHRIM, 2006).

The number of disasters and people affected is anticipated to increase with the onset of climate change. Hydrometeorological and certain geological hazards are affected by climate change. For example, landslides and subsidence are to a certain extent influenced by rainfall, which is in turn affected by climate change. Higher and extreme run-offs may result in increased risk of flooding, which in turn heightens the risk of landslide disasters in urban areas. Increased flooding, particularly in areas previously not exposed to the hazards could lead to dispersal of contaminants and toxins into rivers where wastewater treatment plants are overwhelmed. Such occurrences are already suspected in recent times and are currently under investigation. The possibility of circulation of environmentally hazardous substances in surface water where industrial sites and landfills are affected cannot be ignored. The consequences could be disastrous if such risks are not addressed.

The Town and Country Planning (Amendment) Act 1995 (Act A933) is the first line of defense in terms of environmental protection, and it can be also be used as a planning response to climate change and disaster risk reduction. Development control involves the regulation and control of planning for projects. This takes into account consultation with and input from several technical departments, prior to the concession of land conversion or planning permission. The local authority consults several technical departments before permission is granted. In addition, the Act requires the participation of the public in reviewing the plans that are formulated, making it suitable as a tool to enhance stakeholder engagement with respect to climate change and disaster risk reduction.

The provision of appropriate and easily understood information regarding vulnerable areas in the future will aid local authorities in making a decision regarding an application for planning permission. Terrain assessment can support planning tools such as the Guidelines on Integrated Environmental Sensitive Areas (ESAs) to incorporate elements of climate change adaptation and disaster risk reduction (Pereira et al., 2006; Halimaton et al., 2007). The use of terrain assessment and Integrated ESAs will ensure landuse that supports the aspirations of climate resilient-development, particularly when used in conjunction with existing landuse planning mechanisms in urban areas.

In order for terrain assessment to be effective, the current information on susceptibility, which represents the intrinsic weakness of a system, has to be expanded. The assessment has to include potential interaction with climate related stressors. The priority should be to identify highly susceptible on urban areas. Based on this initial screening, socio-economic dimensions such as exposure, coping capacities and adaptive capacity have to be assessed. This is not currently done by any organizations in the country. There are many aspects to be taken into account at the assessment level, incorporation of findings into planning and decision-making processes and subsequent implementation. These include handling of uncertainties, harmonizing scale of information, governance with respect to participatory planning and stakeholder consultation, education, awareness and communication of risks, emergency response and early warning as well as limitation of resources, knowledge and technology. In addition to this, there is the challenge of ensuring effective interactions between adaptation and mitigation.

4. CONCLUDING REMARKS

The National Policy on Climate Change and the National Policy on Green Technology accepted by the Cabinet of Malaysia in 2009. The establishment of the National Green Technology and Climate Change Council, chaired by the Prime Minister of Malaysia has served to mainstream the issue of climate change and bring about new institutional arrangements. The issue of balancing adaptation and mitigation can be addressed more effectively, to better serve the country. The revitalized policy and institutional domains provides an opportunity address climate change adaptation and mitigation at the macro and sectoral levels.

Spatial planning responses provide an opportunity for adaptation-mitigation interactions. However, in the immediate focus should be on adaptation. Research initiatives should be embarked upon that bridge the science-governance interface. Platforms that link and create synergies between researchers, practitioners and other stakeholders should be strengthened. Concerted, systematic and purposive efforts should be made to enhance education and awareness, in conjunction with stakeholders at the appropriate levels. All these efforts will make a significant difference to the country in the context of climate-resilient development.

REFERENCES

Birkmann, J., 2007. Risk and vulnerability indicators at different scales. Environmental Hazards (2007), doi:10.1016/ j.envhaz.2007.04.002

Chow, W. S. and Ferdaus, A., 2000. Geological inputs for the development of the Payar Terubong – Relau area, Pulau Pinang. In: Teh, G.H., Pereira, J.J. and Ng, T.F. (Eds.) Proceedings of the Annual Geological Conference 2000, Geological Society of Malaysia, Kuala Lumpur, 249-260.

Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li & N. Huu Ninh, 2007. Asia. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 469-506.

Government of Malaysia, 2009. National Policy on Climate Change. Ministry of Natural Resources and Environment, Putrajaya.

Halimaton S.H., Pereira, J.J. and Komoo, I., 2007. Sustainable City Planning – Emphasis on Management of Environmentally Sensitive Areas. *Journal of the Malaysian Institute of Planners*, 5, 61-76.

IPCC, 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

Ismail Ibrahim, 1996. Pindaan Akta Perancangan Bandar dan Desa dan Laporan Cadangan Pemajuan [Revision to the Town and Country Planning Act and Development Proposal Plan]. *11th Senior Officials Meeting of the Town and Country Planning Department, Kuching, Sarawak, 2-5 October, 1996*. Organisers: Town and Country Planning Department of Peninsular Malaysia and the Government of Sarawak.

Jamaluddin, M.J., 1986. Human Perception and Responses to the Flash-Flood Hazards in Parts of Kuala Lumpur. In: Sham Sani (ed). *A Study of the Urban Ecosystem of the Kelang Valley Region, Malaysia, Vol. 1 - The Kelang Valley Region: Some Selected Issues,* 84-104.

JMG, 2006. Geological Terrain Mapping Manual. Department of Minerals and Geoscience Malaysia, Ministry of Natural Resources and Environment, Kuala Lumpur. 69 pp.

National Hydraulic Research Institute Malaysia (NAHRIM), 2006. *Study of the Impact of Climate Change on the Hydrologic Regime and Water Resources of Peninsular Malaysia – Final Report.* Ministry of Natural Resources and Environment, 184 pp.

Pereira, J.J. and Komoo, I. 2004. Sustainable Management of the Physical Component of Urban Ecosystems: The Malaysian Perspective. *In:* Miller, D. & de Roo, G (Eds.) *Integrating City Planning and Environmental Improvement-Practicable Strategies for Sustainable Urban Development (2nd Edtn.).* Ashgate Publishing Ltd., Aldershot, 115-126.

Pereira, J.J., Halimaton S.H. and Komoo, I., 2006. Management of Environmentally Sensitive Areas. *In:* Halimaton, S.H. & Norliza, H. (Eds.) *Planning a Developed State-Development Planning for Sustainability*. Selangor State Government, Shah Alam, 13.1-13.13.

Tompkins, E. L. and Adger, W. N., 2005. Defining response capacity to enhance climate change policy. *Environmental Science & Policy* 8, 562-571.

UNISDR, 2004. Terminology Basic Terms of Disaster Risk Reduction. In: Living with Risks: A Global Review of Disaster Risk Reduction Activities, UNISDR, Geneva (Revised 2009).

UNISDR, 2005. Hyogo Framework for Action, 2005-2015. In: Building the Resilience of Nations and Communities to Disasters, UNISDR, Geneva.

Wan Azli, W.H., S.Mohan, K. and S. Kumarenthiran, 2008. Climate Change Scenario Climate Change Scenario and the Impact of Global Warming on the Winter Monsoon. In the *Second National Conference on Extreme Weather and Climate Change: Understanding Science and Risk Reduction*. 14-15 October 2008, Putrajaya, Malaysia.

Climate-related and other Hazard-related Urban Risks in Coastal India – An Overview on Specific Study Sites

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ABSTRACT

Important coastal cities – Chennai and Mumbai are located on east and west coasts of India, respectively, are witnessing the fury of climate change induced disasters like cyclone and monsoonal floods especially from the year 2005. Invariably all the coastal cities in both east and west coasts of India are having the similar threat due to climate change and future sea-level rise and other climate change induced disasters like drought and monsoonal floods. Especially due to unplanned urbanization and rapid developmental activities along the coastline both cities are now witnessing erosion and accretion of their coastlines, which is now being treated as a chronic disaster and the same is expected to aggravate in the future due to sea-level changes. This paper is aimed to review the core issues and concerns related to urban risks in Chennai and Mumbai. .

Keywords: ***coastal urban centers, multi-hazards, chronic disasters, urban risk***

1. INTRODUCTION

The coastal zone includes both land as well as the adjacent water part, which are usually dynamic in nature and strongly influenced by each other, and also more susceptible to hazards induced by natural as well as man-made processes. Coastal locations were some of the first settled in India and have always accounted for population concentration as well as population explosion apart from the place for future areas of expansion. Due to rich in biological diversity, coastal areas housing large number of hot spots such as reserves forests, national parks and marine biosphere reserves. Due to the rapid economic expansion expected in developing world cities, the highest asset exposure is projected to become more concentrated in Asian cities, with eight of the top 10 situated in this region: Guangzhou, Kolkata (Calcutta), Shanghai, Mumbai (Bombay), Tianjin, Tokyo, Hong Kong and Bangkok. Out of these ten cities, 2 are situated in coastal areas in India. Seventeen out of the 20 cities with the expected largest proportional increase in asset exposure by 2070 are located in Asia. They comprise both mega-cities and current second-tier cities www.cat-risk.com. Since urbanization is an irrecoverable process the reality of urban risks especially during floods are witnessed in a majority of the coastal cities in India after 2004. However, the influence of biophysical factors like coastal landforms, land elevation, water ways, wave and tide conditions etc are more in controlling as well as aggravating urban risk due to natural and man-made disasters. Most of the coastal cities along east coast of India are prone to climate-related disasters, which is mainly due to low elevation, gently sloping topography, occurrence of water ways, backwaters, estuaries and marsh land areas which provide scope for informal settlements / encroachments.

Urban economic imbalances especially the urban poor being forced to settle over more vulnerable localities even by knowing the risk and other environment related hazards. Due to the availability of limited space, coastal cities like Chennai are expanding horizontally and new townships are emerging in the southern part of this coastal city. Also the natural beauty and location of the coastal belt attracts multi-story buildings for both residential and commercial purposes, which are now becoming prone for contamination of coastal aquifer due to the overexploitation of subsurface ground water, which leads to incursion of sea water in to coastal aquifiers. Even in normal and below normal rainfall scenarios, Chennai and Mumbai will experience more droughts and scarcity of potable water during the summer period.

The Bay of Bengal is one of the major centres of the world for breeding tropical storms while a few strike the west coast of India, mainly the Gujarat and North Maharashtra coast. Out of the storms that develop in the Bay of Bengal, over 58 percent approach or cross the east coast during October – December. Cyclones over the Bay of Bengal usually move westward, northwestward, or northward and cross the east coast of India or Bangladesh. Though the east coast of India is more prone to cyclones, as natural barriers like coastal dunes and mangroves are more in east coast when compared to west coast. Severe alteration of these natural barriers especially in urban centres due to urbanization and industrialization makes coastal areas more susceptible to climate induced disasters. Also the recent study based on the integration of long-term daily rainfall dataset and high resolution gridded analysis of human population indicates a significantly increasing trend in the frequency of heavy rainfall climatology over urban regions of India during the monsoon season. Urban regions experience less occurrences of light rainfall and significantly higher occurrences of intense precipitation compared to non-urban areas (Kishtawal et al., 2010). Coastal urban areas in India are expected to face the risk due to monsoonal floods almost every year. Therefore, every coastal city is now in a stage to make an attempt to strengthen its infrastructure like storm water drainage system, desiltation and interconnection of urban water bodies, evacuation modalities and shelters, institutional cooperation mechanism, etc to meet the eventualities.

2. COASTAL URBAN RISK MANAGEMENT– ISSUES AND CONCERNS

2.1 Shoreline Changes

One of the major requirements of planning coastal protection work is to understand coastal processes of erosion, deposition, sediment-transport, flooding and sea-level-changes, which continuously modify the shoreline. Multi-date satellite data have been used to study shoreline change and coastal landforms to understand coastal processes. Shoreline is one of the rapidly changing landform along coastal India. The accurate demarcation and monitoring of shoreline (long-term, seasonal and short-term changes) are necessary for understanding of coastal processes. The rate of shoreline change varies depending up on the intensity of causative forces, warming of oceanic waters, melting of continental ice, etc. Shoreline erosion is being considered as a calamity because it causes (i) loss of invaluable land areas and lives (ii) habitation displacement / relocation (iii) loss of beaches and (iv) loss of transport network, infrastructure and other installations. This has been observed in northern part of Chennai coast, where shoreline erosion is chronic and put in to stage for forcible migration of local population. Earlier study (Krishnamoorthy et al., 2001) based on GIS analysis has quantified that nearly 77 sqm of land area along north Chennai coast is being eroded every year due to shoreline erosion, which make the fisher community lives in about 15 hamlets are forced to move from this part.

Figure 1: Shoreline erosion scenario in North Chennai

While considerable land part of this coastal zone is swallowed by the sea due to erosion, the resultant accretion leads to closure of important estuarine mouths in this urban centre. This is an important environmental hazard being faced by this city during the last two decades and the State Government has given special focus to prevent further erosion of this shoreline.

India is one of the pioneering countries in Asia to utilize the satellite imagery to assess the changes in land use / cover, environment and ecosystems including the dynamics of its more than 7500 km length coastline since early 1970s. Due to the advancement in remote sensing technology in the country especially the improvements in both spatial and spectral resolution, more site specific studies were carried out including micro level mapping for disaster prone areas. A considerable amount of work has been carried out by various institutions / agencies especially the Space Applications Centre and National Remote Sensing Agency to map the shoreline changes to quantify the rate of erosion and accretion due to both natural as well as made impacts.

The changes in configuration of shoreline due to erosion and accretion lead to its frequent oscillation, which will be treated as a benchmark line especially in zoning the coastal zone for the implementation of Coastal Regulation Zone (CRZ) by the Ministry of Environment and Forests (MoEF). Now the MoEF is taking in to the consideration of horizontal shifting of shoreline due to erosion and accretion with reference to 1967 Survey of India topographical maps and multidate satellite imagery.

2.2 Coastal flooding

After a decade of acute water scarcity in majority of coastal urban cities like Mumbai and Chennai both these cities have experienced heavy rainfall events with increasing frequency of urban floods during South West Monsoon season since 2005. Local governments have taken efforts in implementing rain water harvesting programme through the participation of community to meet out the water crisis. As these cities started growing uncontrollably especially during the last two decades, the land use pattern changed drastically with more vacant areas which have been converted for constructions and other infrastructure facilities. This results in change of urban hydrology from gradual rising discharge to quicker and higher peak flow. Many of the water storage areas have been encroached by human settlements and denudation of water ways during the drought years aggravated the impact of urban floods both in Mumbai and Chennai since 2005.

Figure 2: Encroachments around water body in South Chennai

Mumbai is one of five cities included in the centrally sponsored Mega City Scheme launched by the Government of India in the Eighth Five Year Plan. Like most major urban centres in our country, Mumbai has grown tremendously in the last few decades due to unabated migration from the smaller towns and rural areas. This resulted in a haphazard fashion with little consideration for proper urban planning. Also most areas of the city are lacking basic civic amenities. Slums are considered vulnerable primarily because of their location and density, population concentration and access to infrastructure. Slums are occupying hilltops, slopes, nallahs, low-lying areas with tendency to flood during high tides and monsoon seasons. Some projections state that Mumbai could overtake Tokyo as the world's largest city by 2050 (Shaw, 2008). Mumbai's greatest stress bundle is related to extreme rainfall and floods, such as the heavy flooding that occurred in July 2005. A record of 994 mm rain within 24 hours marooned the entire Mumbai on 26th July 2005. In some low-lying areas, the water was 10 to 15 ft deep. Open gutters and nallahs turned into raging rivers. Thousands of homes in the Mumbai's sprawling slums were either washed away or damaged beyond repair. The middle and upper class were not spared either, with floodwaters entering and even completely submerging ground floor apartments in many areas (Conservation Action Trust, 2006). Mumbai's various characteristics of topography (flat), geology (unconsolidated fill material), numerous wetlands and flood-prone areas, the city's building conditions (not meeting building codes, squatter dwellings, previously flood-damaged buildings), poor sanitation and poor waste treatment and removal capabilities together create a particular bundle of stresses that collides with the set of socio-environmental conditions of Mumbai, such that vulnerabilities emerge for the system (www.ihdp.org/publications). Climate model forecasts indicate that extreme precipitation will happen over a large area, particularly over the west coast of India and west central India (Rupa Kumar at al., 2006). Additionally, spatial distribution of temperature changes indicated a significant warming trend which has been observed along the west coast, central India, and interior Peninsula and over northeast India. However, cooling trend has been observed in northwest and some parts in southern India (Gupta et al., 2009).

2.3 Coastal Flooding due to Extreme events - Tsunami

On 26 December 2004, as many as seven countries in Asia were devastated by the Indian Ocean tsunami event, which resulted in more than 200,000 loss of life and several millions of families displaced and property damages of about US $ 10 billion. Among many areas destroyed were urban coastal areas with important infrastructure and lifeline facilities. Chennai on the southeast coast of India is one of the worst affected sites along Tamil Nadu coast. The wave height created by this tsunami resulted in the inundation of urban areas bordering the sea, which not only resulted in loss of life and property damage but also severe environmental hazards due to flooding. Inundation mapping of this tsunami and also the incorporation of land elevation details together with administrative boundary maps clearly brought out the quantitative details on coastal flooding due to tsunami water. Though flooding due to tsunami waves is not an event due to climate related disaster, the vulnerability assessment and the warning system model are useful to study the impact of storm surges and monsoonal floods. Important biophysical factors which influence the control of tsunami water inundation are: (1) land elevation, (2) nearshore topography and (3) presence of water ways like estuary, back waters etc. Apart from these some of the man made structures such as shoreline erosion control measures, harbor structures are also reduced the impact of tsunami wave inundation on the urban coast.

2.4 Environmental hazards

Across India, urban citizens have access to only 105 litres per day of potable, piped water supply, as compared to a minimum basic requirement of 150 litres. Only 43 percent of the population has access to sewerage and septic tank facilities, and only 30 percent of sewerage generated actually gets treated. McKinsey Global

Institute Report (2010) claims that this is true also for large cities like Mumbai, which treats only 30-40 percent of its sewage today. Another key urban pressure point is affordable housing. Nearly 80 million people live in slums across the country. This report forecast shows that all cities in the country are expected to face the surging demand for civic services like water supply, sewage treatment and solid waste management.

India could by mid-century, have both the largest national urban and rural populations of the time. This will have an important bearing on global climate vulnerability and the potential for mitigation and adaptation. Hence, the future direction of Indian urbanization, is not only an important domestic concern, but will be major international opportunity to demonstrate the viability of a more sustainable development. It is possible, that climate change induced drought and resource conflict may force the pace of rural-urban migration over the next few decades. "Alternatively, severe stresses induced in urban areas due to a mix of water scarcity, environmental services breakdown, flooding and consequent water borne disease and malaria-like epidemics combined with a rapid rise in health expenditures could maintain the low current level of rural-urban migration" (Revi, 2007, pp 209). "The risks to human settlements could be reduced if people and enterprises are encouraged to move away from the coast, or at least from the most risk-prone coastal locations (this would also reduce the pressures human settlements place on coastal ecosystems). Experience after the Indian Ocean tsunami of 2004, in which over 200,000 people lost their lives and millions more their homes, has demonstrated the profound difficulties involved in instituting more restrictive coastal settlement policies without further undermining the lives and livelihoods of the most vulnerable residents" (McGranahan et al, 2007, pp 21). Tsunami vulnerability assessment also proved that there are certain areas of urban coast in Chennai classified as unsafe (Krishnamurthy et al., 2009). Future planning and developmental activities in these vulnerable zones need to be controlled including safe relocation of vulnerable community through a bottom-up approach.

Sedimentary budget studies of coastal environments are one of the main tools used to define the actual trend of coastal geomorphological evolution and for the evaluation of the impact of human intervention. Littoral sedimentary systems, especially beach and dune areas, are dynamic environments which change according to waves, water currents and the wind regimes that built them. "Energetic events may cause a temporary state of disequilibrium but as long as the boundary conditions remain stationary, sediment can be reworked and adjusted back towards the pre-disturbance morphology" (Alejo et al., 2005, pp 64). However this may not be applicable in large scale intervention of human activities like construction of port and harbors which alters the shoreline in an irrecoverable stage. Additionally, this aggravates the erosion rate as well as deposition on the other part of the coast making the coast to undergo a chronic disaster, which ultimately makes the people to migrate / relocate.

Recent studies on climate forecast also confirm that very heavy and extreme rainfall events show increasing trends over both urban and rural areas, but the trends over urban areas were larger and statistically more significant. According to current forecasts, sea levels will gradually but inexorably rise over the coming decades, and this will place large coastal urban populations under threat around the globe. The Coromandel coastline is more cyclones prone, with 80 per cent of the total cyclones generated in this region. Coastal wetland ecosystems, such as salt marshes and mangroves, are especially threatened where they are sediment starved or constrained on their landward margin. Urban flooding risks in developing countries stem from a number of factors: impermeable surfaces that prevent water from being absorbed and cause rapid run-off; the general scarcity of parks and other green spaces to absorb such flows; rudimentary drainage systems that are often clogged by waste and which in any case are quickly overloaded with water; and the ill-advised development of marshlands and other natural buffers. When flooding occurs, fecal matter and other hazardous materials contaminate flood waters and spill into open wells, elevating the risks of water-borne, respiratory, and skin diseases (Balk et al., 2009).

4. THE WAY FORWARD

The increasing frequency of natural disasters and their tremendous impact on poor communities confirm that disasters continue to be one of developing world's unresolved problems and a major challenge for sustainable development through poverty alleviation. The first steps towards addressing disaster management in an organized and coherent manner were taken with the passage of Disaster Management Act 2005, and the establishment in 2005 of the National Disaster Management Authority (NDMA). Many Indian states are now in the process of formulating state and district disaster management plans. The country has the potential to use remote sensing satellite imagery for mapping and monitoring coastal areas through variety of sensors on board including making near real time assessment of coastal hazards apart from having tsunami and storm surges warning systems in place. All the maritime states are invariably entrusted the task of preparation and implementation of Integrated Coastal Zone Management (ICZM) plan during the last decade. The right use of remote sensing and GIS technology tools helped to prepare Coastal Vulnerability Index (CVI), for example, the Orissa State on the east coast has already prepared CVI map (Srinivasa Kumar et al., 2010). As per this study 22 percent of Orissa coast is highly vulnerable to natural as well as man-made hazards and disasters.

Similar studies with reference to Tsunami vulnerability has also been carried out for Tamil Nadu, which considered the important physical parameters i.e land elevation and near shore bathymetry along with inundation boundary. However, wave height will be an important physical parameter along with land elevation and ocean floor topography. Hence the national programme on establishment of early warning system for tsunami and storm surges has developed a wave model based on these parameters to study the vulnerability of India's coast more quantitatively (Krishnamurthy et al., 2010). Under the initiative of Kyoto University, the Climate and Disaster Resilience Index (CDRI) for 12 Indian cities located both on the coast and inland areas were carried out (India City Profile, 2010). This initiative has brought out initial results on the resilience capacity of these cities with reference to climate related disasters. As a follow up under this initiative and one of the first attempts in India, Kyoto University prepared a first consultation CDRI report for Chennai zones jointly with the Chennai Corporation and the University of Madras. Since there is a definite link between urban disaster and climate risks, the concept of climate resilience presented in this report aimed to assess the urban disaster risks comprehensively in adopting a multi-stakeholder approach in order to build resilience. This study takes an innovative attempt to measure the resilience of Chennai to climate-related disasters (floods, cyclones, heat waves, droughts, etc.) by taking a truly multi-sectoral and developmental approach. Based on five dimensions (physical, social, economic, institutional, and natural), the focus in this study is to understand the capability and condition of the ten zones of Chennai to cope with such events. In this approach, the belief is that micro-level analysis is best in addressing urban disaster risks adequately and comprehensively in order to build resilience. The report provides the base information that can help to build such resilience through taking appropriate action (CDRI, 2010). Actual utilization of resilience study report in the field by the local government needs to take it as an integral part of community development, coastal management and disaster management domains. Also multi-stakeholders participation is important to take resilience study as a national approach (US Indian Ocean Tsunami Warning Program, 2007). The efforts taken towards the preparation of ICZM for maritime states will be used as a base for DRR in coastal urban centres. It is note worthy that several coastal cities in the country have taken field based activities in tackling climate induced disasters in the form of storm water drainage, shoreline erosion protection measures, rain water harvesting etc. Along with the recent initiatives on CDRI will be highly useful in achieving DRR in the coming years (Figure 3).

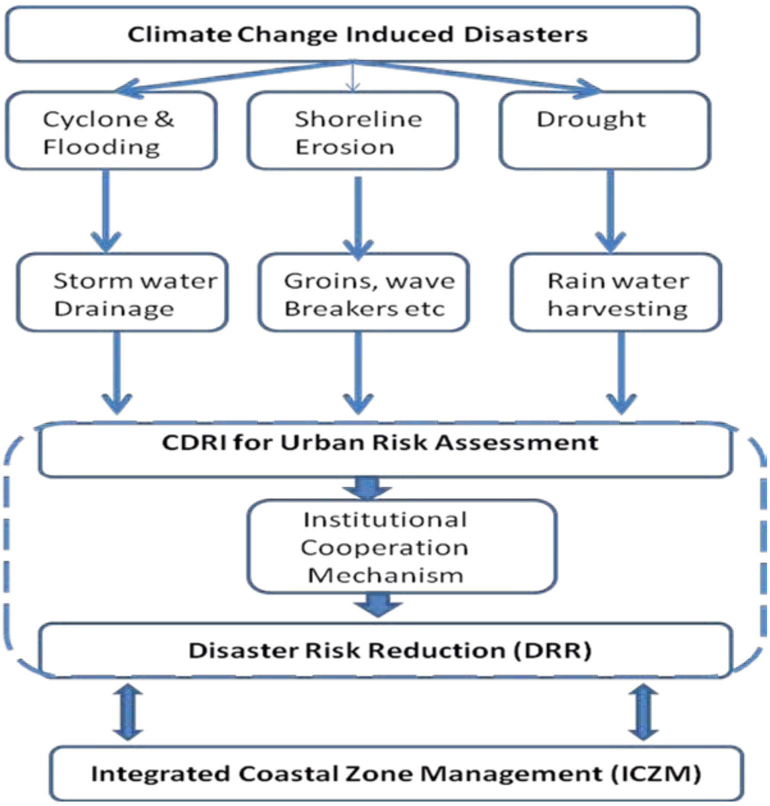

Figure 3: The gap between ICZM and DRR

Among the coastal cities in India, Chennai is pioneering in implementing science based people centred urban disaster risk reduction. Hence the Chennai Corporation is committed to the Global Campaign of Making Cities Resilient, promoted by the United Nations International strategy for Disaster Reduction (UN-ISDR) for the period of 2010-2011. In this context the Chennai Mayor has launched the "Safer Chennai Campaign" with an aim to create awareness to different target groups by strengthening the cooperation and coordination of the city's institutional mechanism. Chennai is taking big efforts to become a role-model city under this campaign and the outcome of this effort is to better control the climate related disasters in the future. Additionally, efforts are underway to prepare multi-hazard vulnerability mapping along with strategies for DRR. The outcomes of these initiatives along with the strengthening of institutional cooperation through the Safer Chennai campaign and CDRI studies are expected to address the climate-related and other hazard-related urban risks in the near future.

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REFERENCES

Alejo, I.,Costas, S. and Vila-Concejo, A. (2005). "Littoral evolution as a response to human action: the case of two sedimentary systems in a Galician Ría", *Journal of Coastal Research*, SI 49, pp. 64 to 69.

Balk, D., Buettner, T., McGranahan, G., Montgomery, M.R., Small, C., Kim, D., Mara, V., Todd, M., Chandrasekhar, S., Baptista, S., and Dorelian, A. (2009), "Spatial Distribution and Risk for Urban Populations: An International Overview", pp. 1 to 40. Climate and Disaster Resilience Index (2010), "Chennai Zone Profile Report", jointly published by Kyoto University, Chennai Corporation and University of Madras, 33pp.

Conservation Action Trust (2006) *Mumbai Marooned: An Enquiry into Mumbai Floods* 2005, Mumbai.

Gupta, A.K., Nair, S.S. and Sehgal, V.K. (2009), "Hydro-meteorological disasters and climate change: conceptual issues and data needs for integrating adaptation into environment - development framework", *e-Journal Earth Science India*, 2 (II), pp. 117 to 132. India City Profile (2010) Climate and Disaster Resilience, Consultation Report, Kyoto University.

Kishtawal, C., Niyogi D.,Tewari M.,Pielke R.A., Shepherd M. (2010), "Urbanization Signature in the Observed Heavy Rainfall Climatology over India", *International Journal of Climatology*, 30, published online Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/joc.2044.

Krishnamoorthy, R.,Bharathi, G.S.,Periakali G.S. and Ramachandran S. (2001), "Coastal zone hazards in India: Study based on remote sensing and GIS techniques", Observing our environment from Space: New solutions for a new millennium, Begni (Ed), A. A. Balkema Publishers, pp. 79 to 86.

Krishnamurthy, R. R., Satheeshkumar, C. and Ilayaraja, K. (2009), "Post-tsunami hazards along the Indian coast", In: Disaster Management – Global Challenges and Local Solutions (Rajib Shaw & R. R. Krishnamurthy, EDs), Universities Press, pp. 86 to 100.

Krishnamurthy, R.R.,Mohana P.,Ilayaraja K.,Dhanasekari K. and Rajkumar J. (2010), "Coastal Vulnerability Studies based on Modeling and Mapping of Tsunami and Storm Surges along Indian Coast", Storm Surges congress, Hamburg, Sept 2010 in press).

McGranahan, G.,Balk, D.,Anderson, B. (2007). "The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones," *Environment & Urbanization*, 19(1), pp. 17 to 37.

McKinsey Global Institute report (2010), "India's urban awakening: Building inclusive cities, sustaining economic growth", 80 pp.

Shaw, R. (2008) "An Overview of Urban Risk of South Asia: Issues, Approaches and Thoughts", *Journal of South Asia Disaster Studies*, 1(1), pp. 69-84. Srinivasa, K.,Mahendra T.R.S.,Nayak, S.,Radhakrishnan, K. andSahu, K.C. (2010), "Coastal Vulnerability Assessment for Orissa State, East Coast of India, *Journal of Coastal Research*, 26(3), pp. 523 to 534.

Revi, A. (2007), "Climate change risk: An adaptation and mitigation agenda for Indian cities", *Environment and Urbanization,* 20, pp. 207 to 229.

Rupa, K., K.,Sahai, A.K.,Krishna Kumar K.,Patwardhan S.K.,Mishra P.K.,Revadekar J.V.,Kamala, K. and Pant, G.B. (2006), "High-resolution climate change scenarios for India for the 21st century", *Current Science*, 90(3), pp. 334 to 345.

U.S. Indian Ocean Tsunami Warning System Program (2007), "How Resilient is Your Coastal Community? A Guide for Evaluating Coastal Community Resilience to Tsunamis and Other Coastal Hazards, U.S. Indian Ocean Tsunami Warning System Program supported by the United States Agency for International Development and partners, Bangkok, Thailand, 144pp. Accessed from http://apps.develebridge.net/usiotws/13/CoastalCommunityResilience%20Guide.pdf on 6th Sept 2010.

www.cat-risk.com last accessed on 4th Sept 2010.

www.ihdp.org/publications last accessed on 4th Sept 2010.

Resilience and adaptation: Coping with climate related urban risk of traditional urban settlement of Bangkok's agricultural fringe.

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ABSTRACT

This research suggests a radical shift in emphasis from the current solid state of landscape urbanism, towards a more systemic approach to urban design based on the dynamic liquid states of waterscape urbanism. Waterscape urbanism is inspired by indigenous water-based cultural practices as well as emerging scientific techniques of monitoring urban systems through watershed frameworks and networked technologies.

The argument about the waterscape urbanism presents Greater Bangkok, Thailand, as a critical case study. Bangkok is one of the most vulnerable and at risk cities in the world already experiencing severe effects of unpredictable climate change. It also presents a degraded, but still vibrant indigenous water-based urbanism that remains a model of resilience and adaptability developed in concert with the historical cycles of monsoon rains and wet rice cultivation.

The analysis and interpretation is that the indigenous methods and practices will provide a good basis for resilience and adaptation for Climate Change Adaptation and Disaster Risk Reduction. Filling up the lowland of the delta and refusing to adjust to the fluctuation of water level in the delta is futile. Being a part of the water – adjusting local practices according to the level of water is a more reasonable approach.

Keywords: waterscape urbanism, resilience and adaptability, indigenous methods and practices

1. INTRODUCTION: THE CHAO PHRAYA RIVER DELTA LANDSCAPE

The meandering river and an endless network of natural streams and manmade waterways comprise a distributory rather than tributary geography in the Chao Phraya delta. Bringing and retaining the water during the dry season and draining the water during wet season the vast network of canals brought life to the delta. The lower part of the Chao Phraya river delta, the geomorphologically younger part of the Chao Phraya river delta, is a part of "the center of the geographical living space" (Tanabe 1977). This view was built upon the capability of the landscape to provide functions or potentials (Zonneveld 1988) for human inhabitation and exploitation, such as the capacity to produce foods and resources, the capacity to build human's habitat and places, a self-regulated environment, based on the resilience of the landscape's ecosystem and the capability to link with aesthetic, scientific, cultural and other interest of human kind.

The landscape of Chao Phraya River delta has been through the processes of modification and transformation becoming early in the 20th century a major part of the world's rice bowl and the undisputed world leader of rice production for export. By the end of the 20th century through conversion and replacement by urbanization and export manufacturing, its inhabitants also have been through long periods of adaptation and resilience in dealing with various kinds of change.

Figure 1: The Lower Chao Phraya River Delta and the city of Bangkok: Watery Bangkok sprawls over an urban agricultural landscape dominated by fruit orchards to the west, rice fields to the east, shrimp farms along the coast and fish farms in the lowlands.

2. THE CITY OF BANGKOK AND LANDSCAPE CHANGES

Bangkok, the capital of Thailand, is situated in a slight deltaic high amidst a predominantly low lying, flat terrain of the lower Chao Phraya River delta. The area was first urbanized during the Ayutthaya period, as a vast network of mixed fruit orchards and market towns planted within a harsh marshland (Tachakitkachorn, 2005). The rapid development of the lower delta for export rice cultivation affected the rapid urbanization of the city of Bangkok (Takaya 1987). In the early years, many canals were constructed and functioned as highways (Takaya 1987). The canals radiated outward from the center of the city, providing access to the city center. Along the canal banks were homes and shop houses. The lands in between were fruit orchards and rice paddies. The early residents relied upon canal and river water for their basic needs (Jarupongsakul and Kaida 2000).

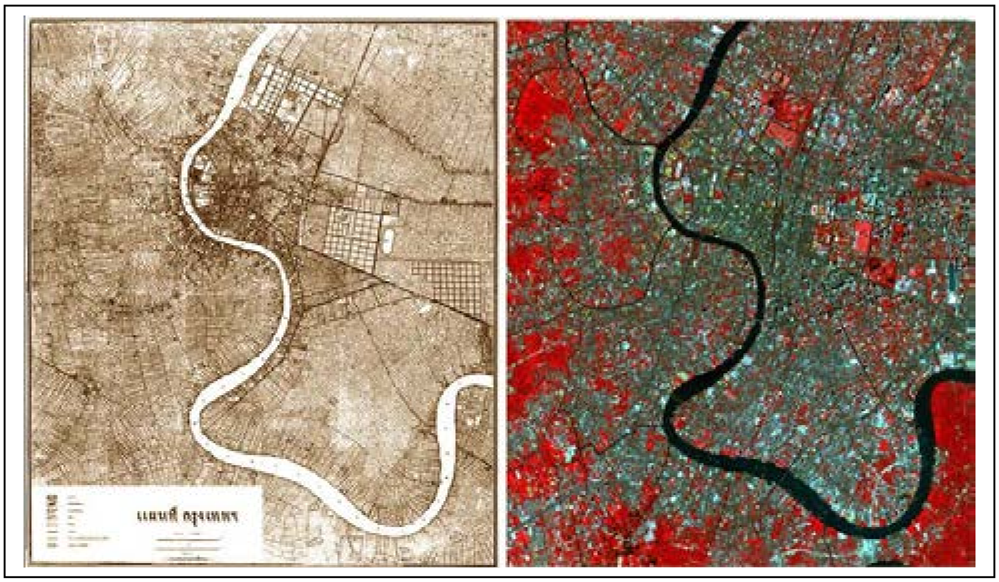

Figure 2: Bangkok circa 1890 (left) and 2004 (right): Bangkok's urban morphology follows the pattern of water-based rice and fruit framing and the wandering Chao Phraya River

During the beginning period of city establishment (1782-1900), Bangkok grew rather slowly. The city's rapid urbanization and increase in population started after the Second World War (BMA 2004). These rapid changes brought the number of land based infrastructure and other constructions that resulted in a rapid increase in built up area (BMA 2004) at the expense of cultivated land and the hydrological matrix. The swift expansion of Bangkok's industry and suburban development occurred in the late 1960s and 1970s. Consequently, the growing demand for housing sprawled eastward into the paddy fields (Jarupongsakul and Kaida 2000). The rapid urbanization also affected the city's unique vast canal network which became secondary to the construction of roadways through the rapid urbanization. The network once considered a lifeline has been neglected and abandoned, yet still fragility persists in many areas. The major mechanism that keeps the delta habitable and prolific has been damaged (Jarupongsakul 2000).

Many canals were filled up for developments or replaced by the construction of new roads, while many others became stagnant and non navigatable, reduced to drainage ditches and open sewers.

Figure 3: Since 1950, road building has far out-paced the canal digging which was the dominant transportation infrastructure for the previous centuries of delta inhabitation.(adapted from Sternstein 1982) The result is a two-level transportation network where the land-based infrastructure dominates and comprises the ability of the hydrological network to operate. In rainy season, the opposite is often the case as annual floods slow and stop traffic in much of Bangkok.

3. THE LANDSCAPE AND THE PEOPLE

Along the 14th parallel, day and night oscillate neatly between predictable twelve hour divisions and months pass with little change in temperature barely affected by the earth's axial tilt. However between May and October, a shift in atmospheric currents brings monsoon rains from the Indonesian archipelago north to the mountain ranges ringing northern Thailand whose runoff feeds the Mae Nam Chao Phraya River Basin - and Bangkok sprawling across its flat, silted tidal delta. Seasonal cycles of precipitation rather than temperature extremes of winter and summer bring rhythm to life just above the equator, putting into motion human cycles of planting, harvest and migration, as well as shaping Thai beliefs and rituals.

Early settlements along the bank of rivers, canals and flood plain areas were subjected to flooding and draught every year. This settlement characteristic was the result of cultural, topographical and hydrological characteristic of the delta. The vast agricultural settlement benefited from flooding without serious problem or flood damage. Flood, a natural process, was a part of life and considered as life's nourishment. People adapted to the rhythm of the natural process by building their living environment according to flooding and draught characteristic without any action against the course of the natural process.

The alteration of the land and waterscape overtime through the course of urbanization and modernization has turned the effect of flooding into a negative impact, especially in urban areas. Flooding has become a natural hazard and considered life and property threatening, although several factors contributing to urban flood are the consequences of human activities. Engineering solutions (structural control) to prevent flooding were introduced at great cost. Unforeseen consequences due to the limitation of structural control have changed the landscape and natural process that have affected the way of life for people to a great degree. Moreover, when the structural control fails, it causes greater damage (Jarupongsakul 2000).

4. THE THREAT AND THE RISK

Lying on the low-lying of the lower Chao Phraya Delta, Bangkok encounters periodic floods every year. As an agricultural settlement in the past, flood, a natural process, was a part of life and considered life's nourishment. Historically people lived in concert with the natural process of flooding as essential to the wet rice growing economy, while the modern city depends on the immediate release of excess rain water, upstream runoff and tidal surge through elaborate technologies of flood control dikes and gates, which too often remain closed to water flows and discharge.

Dictated by the tropical monsoonal climatic conditions and coastal tidal dynamics, the low-lying flat terrain of Bangkok's land-based urbanism is now under the threat of flood during the height of the rainy season. The combination of the excessive flow generated by the rainfall in upland watershed of the Chao Phraya River and the excessive runoff created by the rainfall in Bangkok and vicinity often puts many parts of Bangkok under water. Compounded with the high tide that slows down the flow of the river, the draining of excessive runoff is impossible without the help of modern technology such as floodwalls and pumping stations. The landscape of the area is greatly dominated by these three hydro-ecological characteristics which given the symbolic name of Bangkok as "the city of three waters" (Jarupongsakul 2000). The question and risk Bangkok faces is which way of perceiving these three waters can insure an adaptable and resilient urbanism in the face of the uncertainty of climate change?

The plight of climate change compounds an already complex ecosystem with many conflicts between delta and the city dynamics. More hot days, longer summers, higher rain intensity, more water, and sea level rise (SEA START RC 2007) are among the main concerns in the Bangkok metropolitan area and vicinity. These changes would be compounded by the increasing threats of urban heat island phenomena, periodic flood during rainy season, drought during dry season, loss of coastal land due to coastal erosion, industrialized prawn production, and land subsidence due to industrial ground water withdrawal. The delta and the city presents threats to each other due to a lack of both recognition of natural hydrological processes and the indigenous and traditional knowledge of living in concert with natural cycles of wet and dry seasons. The dynamic of space-time relationships of human and nature has failed to recognize the importance of the hydro-ecology of the landscape of the city.

The vanishing views of natural processes and the vanishing land and waterscape that reflect the relationship between human and natural processes are clearly visible in the Bangkok metropolitan area. These views are also reflected in the recent transformation of agricultural areas to built-up areas in the urban fringe of the metropolitan area. As consequences of these different views, the roles and functions of natural processes and the landscape are perceived differently. These different values play a major role in dictating different changes in the land and waterscape and land and water use.

5. THE FUTURE IN THE PAST: THE INDIGENOUS METHODS

Today, the Chao Phraya River Basin is managed by a vast network of hydro-electrical and draught control dams and reservoirs by ministries in Bangkok rather than tributary kingdoms. Modern dams and huge reservoirs replaced cities as locally controlled and maintained water retention systems modeled on the Tennessee Valley Authority with World Bank and American assistance during the Cold War. Water and floods were thought to be technologically controllable and manageable in a system that is more ideologically aligned with techno-rational models than with the complexities of indigenous Thai socio-hydrology and urbanism.

Thai urbanity and domesticity evolved from intimate association with climatic, topographic and hydraulic conditions. River, canal and lagoon based garden cities retained six months of rainwater for the following six dry ones, staging ceremonies and rituals in sync with attentive observation of hydrological cycles and variations.

The contemporary Bangkok in the context of Thai waterscape urbanism: a pre-modern, locally controlled, human ecosystem watershed model structured and sustained Thai cities for centuries. An animist tradition combined with an inherited Hindu-Buddhist cosmological framework created a tributary culture for a locally managed, forest and agricultural production society with a Dhamma King, as the symbolic Lord of Life symbolized through water. A reassessment of how river and water flows that have been engineered to pass around and under cities rather than through them is critical in order to create new dynamic design models of urban ecosystems. The understanding of historical resilience and adaptability of living with water of indigenous and traditional methods would be crucial for dealing with future uncertainty. This is not just a historical model, but contemporary urban ecosystem designs around the world are looking for ways to retain water in cities (McGrath, 2008). The discipline of landscape and urban planning and design is being added to this framework in order to create new dynamic planning and design models of urban ecosystems. Contemporary urban ecosystem science and Thai urbanism both point to the creation of cities as water retention systems not dams – for socio-cultural as well environmental reasons.

6. CONCLUSION

The urban hydro-agricultural complex of the Chao Phraya River Delta was radically transformed as a result of Bangkok's rapid and expansive urbanization over the last fifty years. While the delta and the city are now in conflict, they were once entangled in a highly resilient absorbent agricultural matrix in concert with climatic cycles of monsoon and dry seasons.

We suggest a radical shifting in emphasis from the current “solid state” of landscape urbanism, towards a more systemic approach to urban design based on the dynamic liquid states of waterscape urbanism. This shift in language also represents a shift in thinking about urban design in the age of rapid climate change. Instead of the design of cities thought of as permanent, stasis, solid land based environments, liquid perception is based on change, adaptation and the continuous reproduction of locality as an embedded and evolving cultural practice. Waterscape urbanism is inspired by the philosophical concept of liquid perception (Deleuze, 1986), indigenous water-based cultural practices as well as emerging scientific techniques of monitoring urban systems through watershed frameworks and networked technologies.

Our argument about the liquid perception of waterscape urbanism presents Greater Bangkok, Thailand as a critical case study. In addition to Bangkok’s status as one of the most vulnerable and at risk cities in the world, already experiencing severe effects of rapid and unpredictable climate change, it also presents a degraded, but still vibrant indigenous water-based urbanism that remains a model of resilience and adaptability developed in concert with the more predictable historical cycles of monsoon rains and wet rice cultivation. Combing new ways of seeing the world, new ecosystem science and the case study of Bangkok liquid perception will contribute to an argument about making a redefined concept of waterscape urbanism central to addressing the social and environmental challenges and risk of climate change.

It would be important for architects, landscape architects and urban designers to understand the difference between these two land and water based models to critically analyze current trends in landscape urbanism. While landscape urbanism has developed an argument around North American post-industrial cities and the creation of large parks as islands in these cities, we suggest the exploration in depth the watershed approach as a new model for urban design, allied with the new modes of perception Deleuze calls for, waterscape urbanism.

Figure 4: Solid and Liquid Perception and Practices

A. A flood wall and water gate blocks an old house from the canal.
B. Traditional houses can be periodically raised above rising flood levels.
C. A new house is constructed on raised landfill and behind a protective wall.
D. A house raising in progress, finding a higher living level.
E. A city trunk canal with reinforcing concrete beams across the canal preventing navigation.

F. An urban fringe canal with a walk way and a fish trap.
G. A city canal and a city street in a business district.
H. An urban fringe canal with waterside shop houses.

Table 1. Solid and Liquid Perceptions and Practices

Solid perception	**Liquid perception**
Rigid flood protection structures inhibit the natural flow of water.	Flexible and open traditional structures allow the natural flow of water.
Life behind the flood protection barriers will be static and stagnant because the structure separates the life behind the wall from the dynamics and nutrient flow of water.	Cultural and social life is tied to the dynamics of water. Social and economic patterns adjusted according to the dynamic level of water.
Resists any changes of water level or quantity.	Resilience and adaptation evolve through time with the seasonal flow of water.
Incoherence between land and water.	Coherence between land and water.
Water is a hazard and need to be eliminated /mitigated.	Water is a part of vulnerability and it is manageable.
Disjointed – separation among land-water-human.	Joined, linked, connected land-water-human.

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REFERENCES

BMA 2004: Bangkok Metropolitan Administration, General Information Website: http://www.bma.go.th/bmaeng/body_general.html#geography, December, 2004.

Deleuze, G. 1986: *Cinema 1: The Movement Image*, Minneapolis, University of Minnesota Press, 1986.

Jarupongsakul, T. and Kaida, Y. 2000: The Imagescape of the Chao Phraya Delta into the year 2020, *Proceedings of the International Conference: the Chao Phraya Delta: Historical Development, Dynamics and Challenges of Thailand's Rice Bowl*: 12-15 December 2000, Kasetsart University, Bangkok, Thailand.

Jarupongsakul, T. 2000: Chapter 2: Geomorphology Aspects Affecting the Occurrence of Floods and influencing the Drainage in the Lower Central Plain, Thailand, in *The Analysis and Preparation for Flood-risk map in the Lower Central Plain, Thailand,* Jarupongsakul, T. edited. Center for Disaster and Land Information Studies, Chulalongkorn University, Bangkok, Thailand.

McGrath, B., V. Marshall, M. L. Cadenasso, J. M. Grove, S. T. A. Pickett, R. Plunz, and J. Towers (eds.). 2007. *Designing Urban Patch Dynamics*. Columbia University Graduate School of Architecture, Planning and Preservation, Columbia University, New York.

SEA START RC 2007: *South East Asia START Regional Center: A Decade of Climate Change Research in Thailand*, South East Asia START Regional Center, Chulalongkorn University, Bangkok, Thailand.

Sternstein, L. 1982. *Portrait of Bangkok, Bangkok*: Bangkok Metropolitan Administration, Bangkok, Thailand.

Tanabe, S. 1977: *Historical geography of the canal system in the Chao Phraya delta from the Ayutthaya period to the fourth reign of the Ratanakosin Dynasty*, CSEAS, Kyoto University, Japan.

Takaya, Y. 1987: *Agricultural Development of a Tropical Delta: a Study of the Chao Phraya Delta*, translated by Peter Hawkers, Monographs of CSEAS, Kyoto University, Japan.

Tachakitkachorn, T. 2005: *A comparative Study on the Transformation Process of Settlement Developed form Orchards in the Chao Phraya Delta*, Doctoral Dissertation Kobe University.

Zonneveld, I.S. 1988: Landscape Ecology and its Application, in *Landscape ecology and Management, Proceedings of the First Symposium of the Canadian Society for Landscape Ecology and Management*: University of Guelph, May, 1987, Polyscience Publications Inc., Montreal, Canada.

IMAGES SOURCES

Figure 1: The Global Land Cover Facility (GLCF), University of Maryland (http://glcf.umd.edu/)

Figure 2: Bangkok circa 1980 Map: Sternstein, 1982. Portrait of Bangkok (page 88)
Bangkok circa 2004 ASTER VNIR image: The acquisition of ASTER data was supported by a research project, 'Investigation of Rapid Urbanization Processes Using ASTER, MODIS, and Landsat Data, by Dr Philip Christensen, Principal Investigator, NASA Grant number: EOS/03-0000-0502.)

Figure 3: Adapted from Sternstein (1982) (page 89)

Figure 4: Danai Thaitakoo

The rapid urban transition in Viet Nam: Challenges for sustainable development in the face of climate change

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ABSTRACT

Urban transition in Viet Nam poses great challenges for sustainable development in the face of climate change. The growing urban vulnerabilities contribute to increasing urban risks in the face of which natural hazards coupled with the possible impacts of climate change are compounded into frequent disasters. Many recent major disasters have occurred in densely populated human settlements in big cities such as Hanoi and Ho Chi Minh City leading to high levels of human, economic, social and environmental loss with a consequent severely negative impact on national and regional development. This paper will present urban environmental risks in terms of urban governance, housing and shelter, urban poverty, infrastructure and natural environment and draw the lessons learned toward a climate resilient city in the context of urban transition in Viet Nam.

Keywords: *climate change, sustainable development, urban risks*

1. INTRODUCTION

Viet Nam's economic growth has the potential to catch up the 'tigers' in East Asia and other Asian developing countries. Nevertheless, Viet Nam entered a period of industrialization and modernization with a range of unresolved environmental problems, particularly due to polluting industries, inadequate infrastructure to manage waste, and worsening natural hazards (Douglass et al. 2002). Along with economic growth, urban transition in Viet Nam also poses great challenges for sustainable development, as the country is considered as one of the ten countries most prone to the impacts of climate change. The growing urban vulnerabilities along with rapid urbanization contribute to increasing urban risks in the face of which natural hazards coupled with the possible impacts of climate change are compounded into frequent disasters. Many recent major disasters have occurred in densely populated human settlements in big cities such as Hanoi and Ho Chi Minh City leading to high levels of human, economic, social and environmental loss with a consequent severely negative impact on national and regional development. This paper will present urban environmental risks and draw the lessons learned toward a climate resilient city in the context of urban transition in Viet Nam.

2. URBAN ENVIRONMENTAL RISKS

The major environmental risks facing Viet Nam's urban areas include contamination by residuals of industrial processes, disposal of domestic and industrial waste, and changing consumption patterns, and natural disasters leading to new types of urban risks in the face of increasing impacts of climate change. Even in its relatively early stage of industrialization, the face of the cities and the industrial zones has already changed very quickly. These changes and their environmental impacts are most acutely observable in major cities like Hanoi and Ho Chi Minh City (HCMC).

2.1 Solid waste

Solid waste collection and management represents a crucial issue in many major cities, particularly in Hanoi and HCMC, the two cities with the largest generation of solid waste in Viet Nam. The volume and types of wastes generated in urban and rural areas have changed over the past decades. This change reflects a major cultural-shift taking place in Viet Nam; the shift from a low consumption, thrift based society whose products were largely derived from organic materials to a high consumption society whose products are largely inorganic materials and come from industrial processes. The shift of waste generation is extremely important since it has many impacts on environmental management, health issues, and often breaks down inherited waste management practices based on symbiotic rural-urban exchanges and uses of organic wastes.

Up to the mid-1980s, waste treatments in urban and rural areas of Viet Nam were similar in many ways. Most waste was organic and treated as livestock food, fuel, or was simply buried on house plots. Small fractions of wastes that had value (e.g. waste paper, scrap metal, glass bottles, and bicycle tires) were retained for sale to itinerant junk buyers. In urban areas, sanitation companies were responsible for the collection and disposal of the remaining fractions of solid waste through regular street sweeping and transport to open dumps (which generally former clay pits and fishponds within the urban boundary). Since the early 1990s, this system of waste management has been forced to deal with new type of wastes generated by the growth of an unevenly affluent; consumption oriented, and industrialized society.

Figure 1: Solid waste in Hue City

Transitions in both rural and urban lifestyles have increased waste loads, increased the need to segregate waste, and increased the need to improve waste treatment. So far, there has always been a gap between solid waste generation and the collection process. However, urban solid waste generation, which mainly is municipal solid waste, has increased at a higher rate, widening the gap between waste generation and collection rates.

2.2 Deforestation and land degradation

The loss of forestland in Viet Nam is a very serious problem for a number of reasons. Forests prevent soil erosion, regulate natural water sources, regulate a region's climate, and provide numerous and valuable sources of plants and animals. As a result of the degradation of Viet Nam's forest lands, there has been an increase in flooding and drought, rivers and irrigation channels are silting faster, the country is losing bio-resources, and lands are becoming too degraded for agricultural, with wastelands expanding. The depletion of Viet Nam's tropical forests is changing rainfall patterns since there are now less trees participating in the transpiration and evaporation processes, which return moisture to the atmosphere. Most of these problems are being felt most severely in the highlands, but they will eventually affect the lowlands: as rivers silt up, this affects croplands in the lowlands that depend on these waters. Flooding of cities and metropolitan regions will become more pronounced.

Among the sources of the loss of forest coverage in Viet Nam, many have clear association with the urban transition. While urbanization brings the potential benefits of new markets, commodities and technologies to the usually more remote forested regions, it is also a process that results in quantum increases in demand for natural resources to support the physical building of cities and infrastructure. The extraction of timber and other resources for energy, making cement, supplying water and hydroelectricity to cities all represent profound assaults on rural regions. The city rarely pays the costs of these externalities. However, nor are the costs simply calculable in terms of the loss of trees, but rather are registered in terms of severe ecological disruption, undermining of local food and agricultural systems, and increasing poverty.

In the case of Viet Nam, the rural-urban linkages related to deforestation have become more complex due to past government policies to stem migration to and reduce the population of large cities – especially Hanoi – by resettling people living in very densely-settled regions and cities into the highlands. The government policies outlined above had a number of ancillary goals. One was to reduce the size of southern cities. Second, the encouragement of North-South movement was thought to reduce the overcrowding of the northern regions of Annam and Tonkin, and particularly the Red River Delta. These plans also included the objective of moving settlers from the lowlands to the highlands, including mountainous border regions. In addition to decreasing the population of Viet Nam's cities, the government sought to urbanize the countryside by creating agro-industrial communities.

2.3 Regional flooding

The prolonged flooding of the Mekong River Delta is an important issue for all regions adjacent to the Mekong River. The rever provides the larger regional context for what is undoubtedly the core urban region of highest economic and population growth for the nation. Guiding urban expansion in concert with managing the water system of the Delta is one of the most formidable problems faced in the urban transition. Catastrophic flooding has recently hit HCMC and other Southern provinces. This region is a densely settled area that is growing rapidly due to increasing population in the communes and also in-migration.

Unlike Hanoi and its surrounding urban areas, cities and towns in the Mekong Delta are currently less well connected to HCMC. However, this region is likely to experience a rapidly booming population in the next few decades and will invariably begin to try to link up more fully with HCMC in terms of transportation of agricultural commodities and access to seasonal and part-time employment as well as to higher order services and government functions. Without more attention given to managing the incipient rural-urban linkages across the Mekong Delta, the type of disasters now being experience will surely magnify.

For decades, the floods along the Mekong River have been a way of life for millions of Southern Vietnamese; floods arrive each year with the summer's monsoon rains. Often referred to as the Greater Mekong Subregion (GMS), the Mekong river system is a direct part of the livelihoods of approximately sixty million people, providing “food, water, transport and economic sustenance” (IRN, 2001). The flood-borne sediment provides the food that maintains one of the world’s most diverse fisheries in Cambodia, and also serves as a natural irrigation system for the region’s “rice bowl”, which is responsible for half of all the rice grown in Viet Nam. For centuries, farmers, fishermen, and others have made the river and its vast delta their home. A majority of the floodwater discharges into the South China Sea through the Tien River and the Hau River, the two branches of the Mekong River in Viet Nam. Along the path of the Mekong River through Cambodia and Viet Nam to its delta is a maze of seasonally flooded pastures, woodlands and natural flood reservoirs known as bengs. These act like natural flood regulators, absorbing part of the monsoon floods and, equally important, increasing the dry-season flows of the river (Gujja, 2001).

The Mekong River’s functions have been hindered by extensive deforestation in the region. Deforestation increases the severity of flooding as rainfall on deforested areas washes quickly into river ways instead of being partially absorbed by forests. These 'quick-rising' big floods pose risks to farmers who plant rice and vegetables on the banks of rivers in anticipation of beneficial silt-laden 'slow rising' floods. The UN Economic and Social Commission for Asia concluded that rampant deforestation in the Mekong Delta has resulted in reduction forest cover from 70 percent in 1945 to 25 percent today. In addition, as previously noted, natural forests are constantly shrinking in Viet Nam as a whole. The fear is that, in the context of the low capacity in the past to prevent serious deforestation, an acceleration of unfettered market-driven economic development will worsen such disasters.

Figure 2: Floods in Ho Chi Minh City and Hanoi,
source photo AFP/Getty Images

The flooding in 2000 has caused a great deal of suffering for the inhabitants of the Mekong River Delta in southern Viet Nam. The floods have submerged 214,800 houses, nearly one third of which have collapsed, and floodwaters have prevented 237,000 students from attending school. Even worse, floods have claimed 149 lives (including 128 children); tens of thousands of families are now in urgent need of food and evacuation. In addition, 100,000 ha of rice paddies have been flooded and 28,000 homes damaged. Total losses caused by the floods are estimated at more than US $ 30 million (People in Flooded Mekong Provinces Need Help, 2001). This flooding is acknowledged to be the worst disaster in recent decades in Viet Nam.

Beginning in the Tibetian Himalayas, the Mekong is the largest river in Southeast Asia. Viet Nam is the last country through which the Mekong River flows before it ends its 4,200 km journey to the South China Sea. Since the transboundary watershed area is shared by numerous countries, whatever happens along the flow path of the Mekong will affect the livelihood of communities downstream. One mounting concern is global climate change that contributes to the seasonal setting of hydrological trends. Specifically, the warming global temperatures can lead to faster snow melt along the headwaters of the Mekong in the Tibetian Plateau, triggering flash floods.

So far, the construction of dams has been proposed as a method to control this devastating flooding. Dams are thought to mitigate floods and provide adequate supplies of water during droughts. In addition, the Mekong River has also long been viewed as a potential source of hydropower. Hence, dam construction along the Mekong has the additional purpose of producing electrical power, which will be increasingly needed as cities expand and industrialization proceeds. This is perceived as a commodity, which could even be sold to other nations to add to national income. However, the entire Mekong project has been the subject of high controversy for decades. For Viet Nam, the dams may bring numerous environmental consequences to downstream areas, including changes in the flow regimes of the river and erosion or siltation problems. The downstream countries, Cambodia and Viet Nam, are the most vulnerable ‘victims’ of these changes, as fisheries and agricultural yields in these countries are largely dependent on the normal water flow cycle of the Mekong.

At the same time, intensive logging has been implemented to clear the area that will be submerged in the dam reservoir. Studies show that river catchment areas that are largely deforested or wetlands that have been drained create very different hydrological regimes (Gujja, 2001). When this factor is added to the climate change, as already discussed, it appears to be affecting the timing and pattern of the rainfall. Eventually, the rainfall may become more erratic. In this regard, the timing and volume of expected flooding are becoming more unpredictable. In addition, dams are often built without adequate spillways to cope with extreme floods. In some cases, expected floods were greater than those that the dams had been built to discharge over their spillways.

As a result of all these factors, severe flooding is a serious environmental risk confronting communities in the Mekong Delta, and the severity of flooding has increased in recent decades. The increases in the unpredictability, frequency, and magnitude of floods have been responsible for high human and material costs in the delta. As part of the many risk transitions underway in Viet Nam, natural disaster has been added to the lists of unresolved environmental and health problems accompanying economic development. As with many of the great urban regions in the world, the economic and political logic of the growth of Viet Nam's largest urban region is confronting an environmental reality that defies quick or easy solutions. While much effort has gone into inhibiting migration to HCMC proper, this does not anticipate the larger process of urbanization that will take place in the Mekong Delta. There is thus a need to look more realistically at the likely rather than contained growth of this region to better manage urbanization and environmental management together.

2.4 Air quality

The major source of air pollution in Viet Nam is from industrial emission and vehicular traffic. Hanoi and Ho Chi Minh City (HCMC) are the two largest and most densely populated cities in Viet Nam. Industrial zones are concentrated and emerging in and around Hanoi and to an even greater extent in HCMC. Formerly, many enterprises and plants were located away from population concentrations. Due to the expansion of cities into urbanizing peripheries, however industrial zones are now situated among densely populated areas and cause serious air pollution in neighboring communities. For example, the Thuong Dinh industrial zone, the biggest old industrial zone in Hanoi, was initially located far from inhabited areas. Today, densely populated areas have grown up in areas near the plants such as Thanh Xuan Bac, Thanh Xuan Nam, Kim Giang and so forth. The enterprises are mixed with residential areas and thus inhabitants are threatened by more severe exposure to poor air quality (Douglass et al. 2002).

Indicators of poor air quality in Hanoi and HCMC include dust, particularly from constructions and industrial processes; sulfur dioxide (SO2), which mainly comes from coal as one of Viet Nam's major sources of fuel; nitrogen oxide (NOx), carbon monoxide (CO), and particulates, which are generally emitted from the motorized vehicles' engines during the combustion processes.

The spreading construction processes, traffic, and many industrial processes have been generating high levels of dust in the air. Levels of suspended dust pollution in the air that are just equal to or lower than the permitted norm have only been noted in places located far from cities, industrial zones or traffic axes. In addition, as many new industrial zones are developed, the amount of noxious gases in the atmosphere of cities is increasing as a consequence of the greater industrial processes.

Transportation is another major source of air pollution in Hanoi and HCMC. Although in comparison with other countries, the density of vehicles in both cities is not high, vehicles use is increasing rapidly. In the late 1980s, roads in Hanoi and HCMC were filled with bicycles, pedicabs, and occasionally by trucks or other motorized vehicles. This situation began to change in the early 1990s when the number of motorcycles on city streets began to increase and replace the number of bicycles.

2.5 Water quality and supply

In terms of sufficient water supplies that meet quality standards and sustain human life, livelihood, and for ecosystem balance, Hanoi and HCMC are moving towards a crisis point. These two cities have varied modes of water resources, such as rivers, lakes, groundwater, and springs. However, water sources are being degraded through four main sources: agricultural chemicals, urbanization, industrial waste, and poorly managed dumpsites. While some impacts are clearly urban or rural, many occasions of water quality degradation occur across environmental settings due to flows of water above and below ground, the location of urban landfills, and the increasing need for urban areas to draw water supplies from distant sources.

The increasing number of urban inhabitants also increases human settlement waste and contributes to water quality degradation. This waste has been the major source of wastewater in Hanoi and HCMC, and adds more than 80 percent of the total wastewater. Industrial waste and waste from hospitals and schools also contribute waste, but at a relatively lower percentage. Most of the urban population is not served by sewerage systems, and alternatives such as septic tanks have not prevented the disposal of waste into urban waterways. In addition, there have been changes in consumption patterns, in terms of consumption levels and the variety of consumed products, which not only increase the volume and variety of domestic waste, but also change waste characteristics from organic to more inorganic wastes. Thus, relying on the carrying capacity of waterways to receive and safely dissolve pollutants and contaminants is no longer a sufficient solution for either the growing amount of already existing pollutants or the mounting ‘new types’ of wastewater.

Rapid industrialization, notably water intensive light industries such as textiles or chemical intensive production such as footwear or ‘high technology’ computer chip fabrication, would add substantially to the degradation of an already overburden water system. Even now, while new industries have emerged in Hanoi and HCMC, most industries in either city, including those financed through foreign investment, have not implemented any sufficient treatment plants. Viet Nam has inherited old industrial complexes, built at a time when environmental concerns were minimal and were using technology dating back to the 1950s.

These problems have become worse since the development of new Industrial Zones (IZs) and Export Processing Zones (EPZs). Viet Nam has currently developed IZs, EPZs, and hi-tech parks in 28 provinces and cities across the country. The IZs were designed to house new factories and re-house those factories and production lines found to be causing pollution in the inner city. However, IZ management boards face even tougher challenges due to the worn-out and outdated equipment used by most of the factories. Moreover, most owners of these factories fail to buy modern equipment or to pay to have their waste treated. Since the level of occupancy in these IZs only reached around 30 percent in 1999 (Le Huong Vong, 1999), IZ management boards may seek to attract new industries and keep current industries by any means possible, which in other countries has meant a reluctance to impose environmental laws or standards. Considering the outdated technology owned by many factories, IZ boards are rarely able to manage an industrial zone as it designed, which would facilitate waste management. They are frequently required to expedite permitting, including environmental impact assessments (EIA).

In addition to above issues, lakes and ponds in Hanoi have been serving as reservoirs of storm water, wastewater, and places for the natural purification of wastewater. The worsening untreated wastewater quality and persistent chemical substances that last in water for many years threaten these lakes; they may become simply wastewater reservoirs. In fact, all of the city's ponds and lakes, with the exception of Hoan Kiem in the city center, have been used for wastewater treatment and aquaculture.

In the case of HCMC, generally most of the waterways are heavily polluted by human settlement waste, industrial wastewater, and solid waste dumped into the canals. The current conditions of these canals illustrate a health risk for people living along the canal. These conditions also threaten paddy field and fish-ponds at the lower stream areas, which is similar to problems around Hanoi.

As mentioned above, water pollution will likely occur across rural and urban environmental settings due to the flows of water. This can be very dangerous in some cases, for example with agricultural chemical pollution, such as pesticides and fertilizers. Pesticides are dangerous to the ecosystem because of their persistent toxic organic compounds. These chemical compounds will persist in nature for a very long time.

Another concern in managing water resources in Viet Nam is how to sustain water quality to adequately meet standards for human use – as drinking water - and for ecosystem balance. A high rate of urbanization and increasing urban populations will lead to substantial increases in the demand for clean water in urban areas. Viet Nam's clean water supplies come from both surface water and groundwater. Viet Nam has abundant water resources but two thirds of these come from external rivers. The distribution of water in Viet Nam is very uneven with variations greatly depending on both differences among regions as well as seasons. However, clean water problems are not merely about matching water quantity with expected demand, but also about how to provide sufficient water that meets clean water standards and contains a proper and efficient distribution system.

Land subsidence due to excessive groundwater extraction has also begun to occur in some areas such as Tuong Mai, which sink at an average rate of 40 mm per year. Ha Dinh, Vong, and Van Dien, meanwhile, are sinking at the average rate of 20 mm per year (Francisco & Glover, 1999). Figure 4.5 shows the location of potential-risk points of severe land subsidence in Hanoi. Most of the areas shown in the map are industrial areas. Since water demands from industries are much higher than residential demands, groundwater will be overly extracted unless environmental risk-costs are internalized.

One extreme example of land subsidence has occurred in Bangkok. Due to the over pumping of the aquifer layer, Bangkok's land levels at certain areas have been reduced by more than 60 cm in the last 50 years (White, 1994:123). As a result, Bangkok's susceptibility to flooding has increased. Flooding occurs almost every year, during the months of October and November, and has resulted in a great misery for residents, as well as enormous economic costs due to damaged roads, telephones, cars, etc. It is very important therefore, that Viet Nam recognizes the early warning signs of this problem and strives to avoid the shortcoming of other countries.

Infrastructure development is another important aspect of water supplies. Viet Nam, like almost all other Asian countries, lacks sufficient water supply service for its cities. The coverage in urban Viet Nam reaches 60 percent of its target with 50 percent Unaccounted-For-Water – (UFW) (ADB, 2001). In many other Asian cities, this condition has resulted in large numbers of un-served urban inhabitants and also decreased revenues for water providers. While still in the beginning of the urban transition, 80 percent of Viet Nam populations still live in rural area. The latest survey shows that only 15-40 percent of rural populations have access to clean water, and only a small percentage of these people have access to sanitary latrines. Shortages of safe water and polluted rural environments have caused many outbreaks of contagious waterborne diseases.

The lack of public water supply services has been compelling people to seek other sources to meet their water demands. This increases the uncontrolled extraction of groundwater by both households and industries. Excessive withdrawal of groundwater will, in turn, create future negative impacts on the city itself as mentioned before. In addition, as people's awareness of the importance of clean water increases, there is a trend of an increasing demand for bottled water, which is said to be processed from springs by private enterprises). Nearly one-third of Hanoi and HCMC inhabitants consume bottled water on a daily basis. Investors have already recognized the potential market for this product, and there have been four companies that are ready to establish this business in Viet Nam (Cohen, 2001).

The trend of an increased use of bottled water presents two important aspects to be considered. First, an increasing demand will lead to an increase in the use of input materials, which in this case are springs as a reliable water source. There is a risk that these companies will over-utilize the resources simply for the sake of their profits, unless resources-costs are internalized in their production. Second, this shift of consumption pattern will adversely contribute to the increase of solid waste generation in urban Viet Nam. Third, as found in the U.S. and Europe where bottled water was not uncommonly below standard levels of safety, such water sold by large and micro enterprises alike requires a routine system of monitoring, presumably by a public entity, which will add costs to water delivery.

The combination of water supply and quality problems forms a list of difficult challenges for Vietnamese society. There is possibility that Viet Nam will repeat the pattern of some other Asian countries; the pace of environmental management and progress lag behind that of economic growth. Since water plays important roles in development processes (e.g., a basic necessity for human beings, and critical for many industrial uses), a sufficient water resource management system should be a prime concern in spatial planning in Viet Nam. This, in turn, will have tremendous economic (e.g. lower costs for public water treatment process) and health benefits for the nation.

3. SPATIAL DIMENSIONS OF URBAN ENVIRONMENTAL RISKS

The accelerated urban-industrial growth that is underway in Viet Nam is bringing new wealth and higher incomes for many people. An unintended effect of this development is the danger that they are bringing new environmental as well as economic risks, making the future of living conditions in the main urban areas as well as rural regions uncertain. In major cities, the rapid growth of the urban population, traffic congestion, unplanned land use changes, uncollected solid waste, and polluted water sources are the most visible signs of the many environmental management problems that are worsening, often at alarming rates.
The changes embedded in the urban and economic transition can be seen as involving a shift in environmental risks from those associated with a largely small-scale agricultural based society to a more modernized, urban-industrial society. The shift involves new sources and quantitative leaps in energy use, notably fossil fuels; transformations from organic to chemical inputs in agriculture; and increasing amounts of non-biodegradable wastes along with toxic wastes -- in sum, forms of air, water and ground pollution never before experienced.

As industries and commerce begin to play larger economic roles in societies that formerly relied heavily on agriculture, forestry and fisheries, life style and consumption patterns change. Along with these changes, society begins to encounter many new types and mixes of risks. As discussed previously, these new risks (e.g. respiratory disease due to industrial air pollution) will add to still existing old and well-known risks (e.g. waterborne disease due to poor sanitary system).

Viet Nam today has entered the most perilous phase of its environmental and health risks. Old risks remain serious or are becoming even worse, and new risks are rapidly appearing. All of these have a pronounced regional pattern of mixes and need to be addressed as such on a regional basis. Some regions continue to face more traditional forms of environmental risk, while more urbanized ones are experiencing the more modern ones. At the same time, the sources of the risks do not necessarily or even primarily come from the localities experiencing. Deforestation of the uplands, which might result in the need for new kinds of fuel for cooking, is often done by distant commercial interests; similarly the introduction of plastic bags that replace organic materials for wrapping, e.g., food, can reach from the city to the most distant outpost. In other words, while the specific mix of risks is particular to each locale, the ways in which risks are transmitted are all part of the spatially integrative processes attending the urban transition.

Many traditional institutions to cope with risks have developed through time in Viet Nam. Rural society in northern and central Viet Nam was characterized by very high levels of risks to individual survival, including threats associated with the natural environment. Responding to these risks, strong social institutions were established to help individuals and communities cope with the frequent disasters that challenged them. Furthermore, it is argued that the "closed corporate" peasant villages of the Red River Delta, in which individual households are tightly integrated into largely autonomous self-managing communities, can be seen as an adaptation to an unpredictable environment characterized by frequent natural disasters (e.g. flood, drought, crop failures), and intense competition for land and other scarce resources.

In contemporary Viet Nam, many of traditional natural hazards still threaten villagers. In some cases, natural disasters had been a part of the villagers' life for decades (e.g. flooding, drought). However, since natural cycles have been influenced by modified methods of managing nature, devastating catastrophes have occurred recently. Flooding in the Mekong River Delta, for example, is a perennial phenomenon. Local societies evolved ways of coping with this annual cycle by implementing a method for "living together with the flood". Houses were often constructed in a certain way to be easily dismantled and transported to safe areas in years of deep floods. Floodwaters also quickly drained away through the vast network of streams and canals that were available in the flood prone area. In recent years, however, the expansion of the road network has created barriers to drainage. In addition, the conversion of flood retention basins to agricultural use has made the impact of floods more serious and longer lasting (Tran and Shaw 2007). Changes of housing in this area into a modern style of masonry structures have also threatened communities; modern style masonry structures mean shelters may be lost to flooding, since they cannot be moved.

In addition to these old and modified traditional risks, modern risks are appearing at a disquieting rate. Many of these new 'modern' risks are discussed above and include increases in amounts and types of air, noise, and water pollution; exposure to agricultural chemicals; and workplace hazards. In the early stage of the urban transition, Viet Nam is also entering a phase of congested risks. Traditional customary practices break down in many cases, while ‘new’ practices are not fully ready to respond to the emerging environmental and health risks. Viet Nam’s related institutions have already been having a hard time coping with traditional risks. Today, these institutions are still poorly equipped and have to face additional challenges from emerging modern risks.

In general, Viet Nam’s current worsening environmental and health problems are the outcome of the interaction of many different factors, including: the natural setting, historical legacies, cultural values, and institutional structures. These factors provide a backdrop for the more recent rapid environmental change brought about by the expansion of the market economy, population pressure, urbanization and industrialization, inappropriate or poorly implemented policies, and lack of adequate knowledge and understanding of the environment. Past policies to control urban growth, such as the restriction of migration, planned decentralization of industry, and the development of NEZ in the periphery, are becoming ineffective and have even exacerbated some problems; they have now largely been abandoned. These conditions foster the rapid growth of cities, which overwhelm existing infrastructures and exacerbate environmental problems. However, these challenges are not merely concerns for urban inhabitants, but also confront households in many communes which are partly industrialized or where localized urbanization is taking place.

4. ENVIRONMENTAL RISKS IN THE URBAN TRANSITION

The economic and urban transition that is underway in Viet Nam is manifest in a shift of the consumption pattern to a higher level and more varied patterns that are acknowledged to represent an increase in wealth and general welfare of society. Today higher order goods such as televisions and motorcycles can be found in very large shares of households. Despite the positive impact of economic growth, there are questions about the increasing trends of urban risks. In general, environmental stress is related to industries, industrial processes and urbanization; all contribute to a sense of cities being overwhelmed by looming crises, with mounting problems exceeding capacities to manage them.

Viet Nam has recently been entering a critical phase, when traditional risks remain serious or even worse, but new risks are rapidly appearing. Before, Viet Nam already had wisdom and social institutions to cope with traditional risks (e.g. stilt houses in flood areas of Mekong delta). But with the shift of risks in contemporary Viet Nam, these customary practices have broken down in many cases. For example, wastewater management methods still follow ‘old customs’ and discharge waste directly into canals. This waste exceeds the water’s carrying capacity to proceed with the natural degradation process. Hence, customary practices do not currently work and at the same time, new methods to deal with the ‘more modern’ problems have yet to be materialized. This phenomenon not only happens in urbanizing rural areas, but also in the cities where most households and industries are not equipped with sufficient waste treatment technologies.

Hanoi and HCMC demonstrate that environmental deterioration is worsening along with the increased urban populations and economic growth. Environmental issues tend to be seen as an outcome of the rapid pace of industrialization and modernization. Thus, environmental management attempts are reflexive rather than anticipatory, falling behind rather than moving ahead of the problems being generated. Implementation problems also appear to be increasing with the scale of the impacts. How to meet current management needs and also scale up environmental management capabilities to reach the level and pace of environmental degradation is a central question in the urban transition.

Economic growth alone has not been able to ameliorate environmental problems, although to some extent it can shift industrial processes towards cleaner technologies and less polluting sectors of production. However, if energy consumption and resource use is still highly inefficient, and are accompanied by failures to internalize environmental costs, then energy and resource consumption will keep increasing as will the production of waste.

Reviewing the trends of economic and urban growth, there have been signs that the two largest cities, Hanoi and HCMC, are continually expanding along with the growth of population and infrastructure developments. Moreover, there have been many spots settlement around these cities that are experiencing local-urbanization and are now becoming densely populated areas. As these ‘urban-like’ areas experience rapid increase in population, they are likely to have the same types of environmental and health problems as those of the urban areas. However, it is important to note that these ‘urban-like’ areas lack the environmental infrastructure and services afforded to the cities. In addition, the customary practices that are still widely implemented in the high density settlements in environmentally sensitive zones are furthering environmental risks in these areas.
A spatial perspective reveals important dimensions of environmental issues. The more obvious insight is that the specifics of these issues vary greatly over space, and thus call for localized capacities to respond to them. Beyond this observation are the many insights from understanding how transformations occurring in one region are resulting from the integration of localities into an expanding urban, regional and global spheres of influence and change. Just as deforestation in the highlands is not taking place in isolation from urban demands for timber, migration from one region to another, and the push for export crop production, the difficulties in sustaining traditional systems of environmental management in lowland areas and cities are not simply a problem of too many people in these locations, but are instead an outcome of gross increases in degree and type of environmental problem linking to broader processes over space. The same is true for the livability of the built environment of cities, including civic and open spaces and housing.

REFERENCES

Asia Development Bank (ADB). (2001). Financing and Developing Environmental Infrastructure in Vietnam: The case of water supply and wastewater treatment. ADB-VRM News Release

Cohen, M. (2001, September 27). The trials and tribulations of a spring-waterbottler in an unpredictable frontier market. Far Eastern Economic Review.
Douglass, M., DiGregorio, M., Pichaya, V., Boonchuen, P., Brunner, M., Bunjamin, W., Foster, D., Handler, S., Komalasari, R., Taniguchi, K., 2002. The Urban Transition in Vietnam, Department of Urban and Regional Planning, University of Hawai'i at Manoa, UN Center for Human Settlements, Fukuoka and UNDP.
Francisco, H. & Glover, D. (1999). Economy and Environment: Case studies in Vietnam. EEPSEA.
Gujja, B., 2001. Dam accused of role in flooding: Research Paper: "Dams and Floods", World Wide Fund for Nature.
International Rivers Network (IRN), 2001. The Asian Development Bank: Financing Destructive Development in the Greater Mekong Subregion.
People in flooded Mekong provinces need help. (2001, October 2). Nhan Dan [On-line]. Available: http://www.nhandan.org.vn/english/today/ouropinion.html
Tran P, Shaw R (2007) Towards an integrated approach of disaster and environment management: A case study of Thua Thien Hue Province, Central Viet Nam. Environmental Hazards
White, R. (1994). Urban Environmental Management: Environmental change and urban design. John Wiley & Son. Inc.

Effect of mix proportions and construction conditions on permeability properties of surface and internal concrete

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ABSTRACT

Reinforced concrete is exposed to environmental conditions which may lead to corrosion of reinforcing steel due to carbonation or salt damage. Durability against these factors is determined by the permeability properties of the concrete. It is generally believed that permeability properties are constant for both surface and internal concrete, but in reality the permeability may vary due to water-cement ratio, cement type, and curing conditions, so it is necessary to understand the effect of these variables on the permeability properties of surface and internal concrete. In this research, a new method for evaluating permeability properties by vacuum pump was developed. This method determines the permeability property based on concrete absorption area and change of weight. The results clarify the effect of the research variables on the permeability property. It was found that curing significantly affects the permeability of surface concrete, and the internal permeability increases as the water-cement ratio increases. For Portland blast furnace slag cement, the importance of curing period for improving the concrete permeability was clarified. Utilizing this examination method may allow for estimation of concrete mix proportions and construction conditions.

Keywords: permeability property, cement type, water-cement ratio, curing period

1. INTRODUCTION

In recent years durability of concrete structures has become more important for reducing life cycle cost. Generally, the diffusion coefficient, an indicator of durability and permeability of concrete, is considered constant in a concrete structure. However, it is believed that the diffusion coefficient at the surface is different than that inside concrete because surface and internal concrete properties differ depending on the water-cement ratio, bleeding property and drying conditions due to curing period. To improve durability against carbonation and salt damage, the influence of these durability factors should be understood.

There are some suggestions for concrete durability evaluation tests; however, those methods are not able to understand the difference between surface and internal conditions. Therefore, a method for easily evaluating the durability on both the concrete surface and interior is necessary. This research aims at the establishment of a permeability evaluation method for the concrete structure and tries to understand the influence of the factors mentioned above. The process of this research is as follows. From the first test, the influence of curing period on water-cement ratio on concrete permeability property was examined. Next, the influence of permeability property considering the difference between concrete surface and interior was evaluated. Finally, using these results the permeability of concrete exposed at a construction site was measured.

2. EXPERIMENTAL OUTLINE

2.1 Permeability test for uniform specimens (Step 1)

Table 1 shows the concrete mix proportions for the permeability test on uniform concrete. To understand curing period suitable for kind of cement, Portland cement and Blast-furnace slag cement which have many shares in the country were used. Materials for mixing were prepared and stored at 20℃ for 24 hours before casting. The test pieces were 100×100×50 mm beams. Figure 1 shows the curing method and period, and the total curing period was 28 days. The period of sealed curing was decided according to the Japan Standard Specifications for Concrete Structures (JSCE, 2007).

Table 1: Mix proportions (air permeability and Slump test)

cement	W/C	s/a	Amount of unit (kg/m^3)								SL	Air
	(%)	(%)	W	C	BFS	S	G	AE water reducing agent	AE	SP	(cm)	(%)
OPC	55	47	172	313	0	855	982	C*0.25%	C*0.02%		12.0	4.2
	45	45	172	382	0	792	987	C*0.25%	C*0.02%		14.5	3.9
	30	42	172	573	0	672	946			C*0.9%	21.5	5.8
BB	55	47	172	156	156	850	976	C*0.25%	C*0.02%		17.5	4.0
	45	45	172	191	191	786	979	C*0.25%	C*0.02%		18.5	4.3
	30	42	172	287	287	663	933			C*0.9%	64×62	4.6

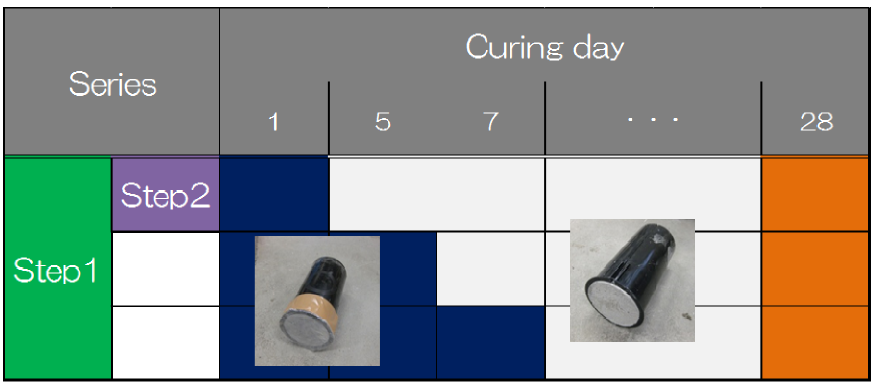

Figure 1: Relationship between curing method and curing period

2.2 Influence of depth in the permeability test (Step 2)

Concrete mix proportions are same as given in Table 1, and the specimens were cylinders ϕ 100 × 200mm. The specimen forms were removed after curing (Figure 1) to understand the relationship between permeability property and depth from surface of concrete. Tests were conducted 28 days after casting.

2.3 Method of permeability test

Figure 2 shows the method for the developed permeability test. After curing, specimens were dried in oven for one day and specimen sides were sealed by aluminum tape to protect from water penetration under vacuum conditions. These specimens were set in a container, and water was poured to half the specimen's height. Specimen containers were placed in a desiccator and vacuum conditions were applied by vacuum pump, which draws water up through the specimens. These specimens were then split in compression and the permeability was evaluated as the ratio of area which absorbed water. In Step 1, the permeability property was calculated as the ratio of water absorption area per all cross sections. In Step 2, it was calculated as the ratio of water absorption area per unit area in which all cross sections were divided into 1-cm segments.

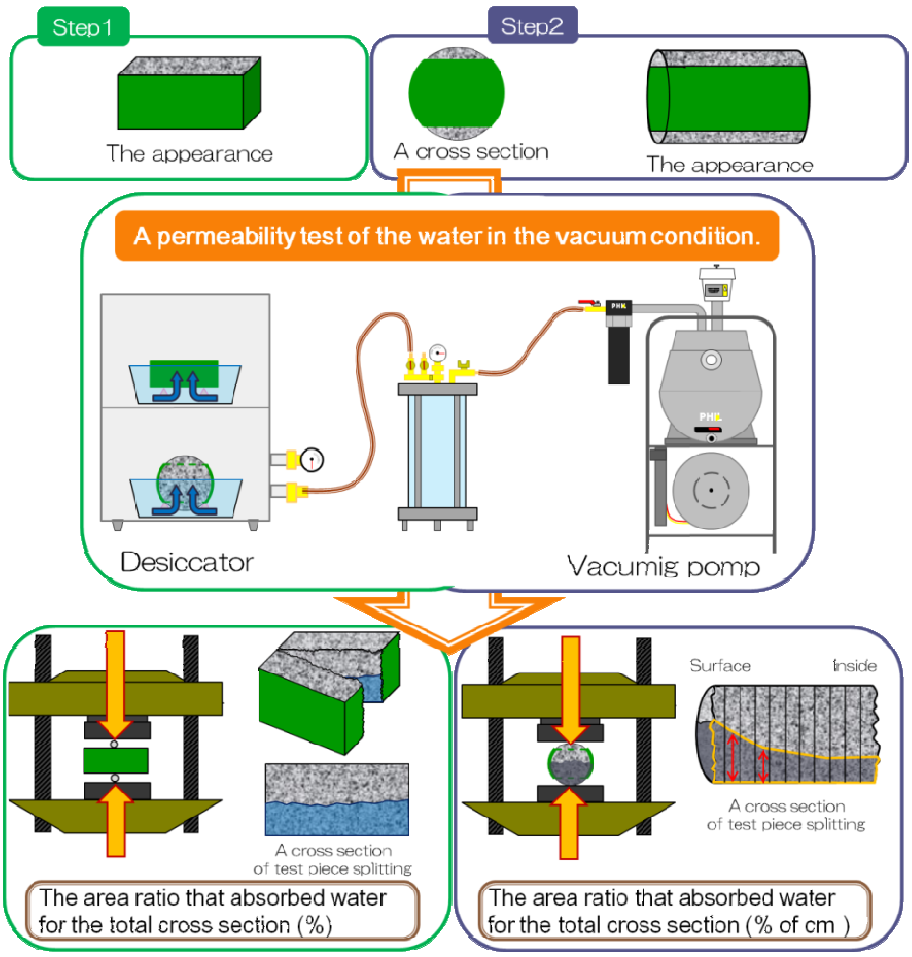

Figure 2: Method of permeability test

3. RESULTS AND DISCUSSION

3.1 Permeability test results for Step 1

Figures 3 and 4 show the results from the new permeability test. For both cement types, permeability property tends to decrease as water-cement ratio increases. In case of high water-cement ratio, the water which is not necessary for hydration increases, so the permeability property was greatly affected by outside condition of concrete. In the blast-furnace slag cement, the permeability property was higher than cement when the curing period was one day. However, permeability properties of both cement types showed a similar result when the curing period was seven days. It is believed that the pore structure changed due to the hydration velocity of the blast-furnace slag cement, which is slower than the Portland cement. These result showed that curing period is important to improve permeability property of surface concrete.

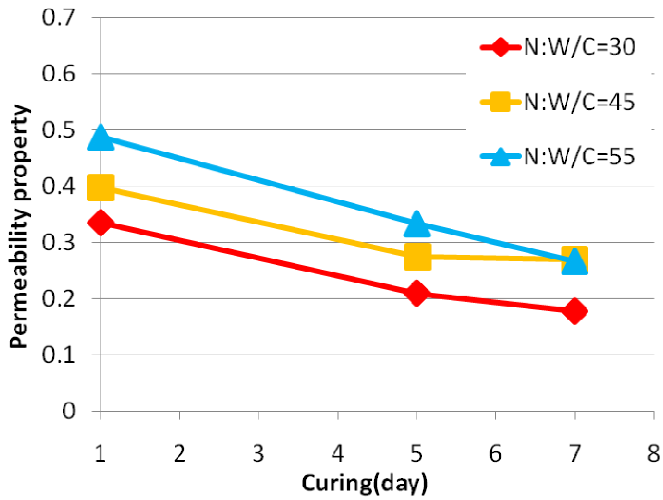

Figure 3: Relationship between permeability property and curing period (Portland cement : N)

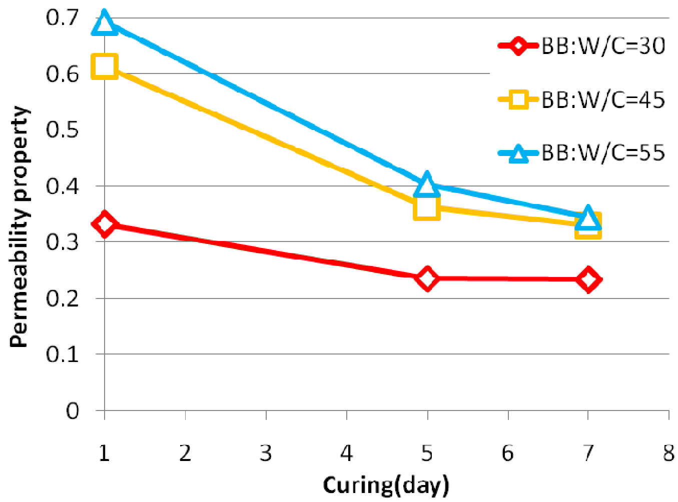

Figure 4: Relationship between permeability property and curing period (Blast-furnace slag cement : BB)

3.2 Permeability test results for Step 2

Figures 5 and 6 show the results of the permeability test for Step 2. Similar to the previous results, permeability property of both cement types tends to decrease as water-cement ratio increases. In addition, the permeability property of both ends of these specimens showed a tendency to become higher by drying from surface. The inflexion point at which the permeability property stopped changing is regarded as the curing influence area; this area (the shaded areas in the figures) for both cement types was about five centimeters. The difference in permeability in the flat area was regarded as the influence of the water-cement ratio because it is not affected by the external conditions. In both figures, the permeability property at both ends (the shaded areas in the figures) was different. It is believed that this difference is due to the difference between casting direction and water transportation direction.

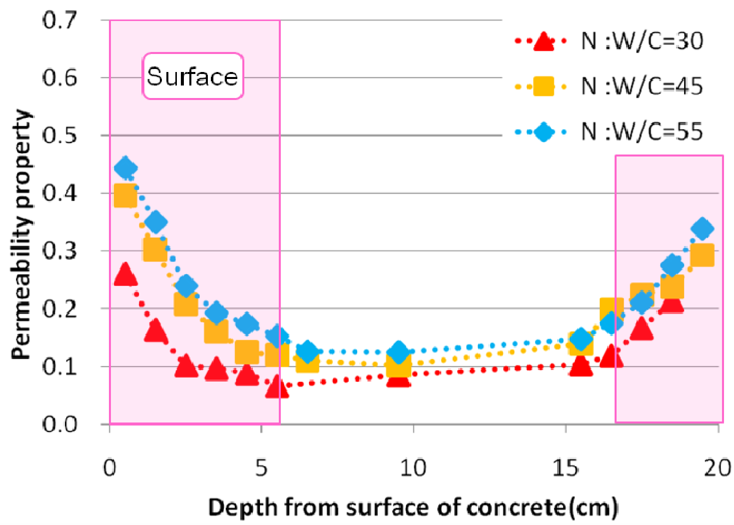

Figure 5: Relationship between permeability property and depth from surface of concrete (Portland cement : N)

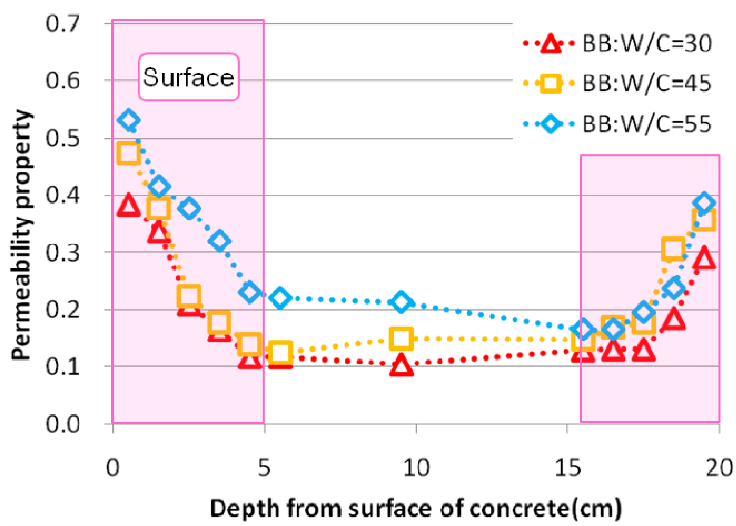

Figure 6: Relationship between permeability property and depth from surface of concrete (Blast-furnace slag cement : BB)

4. Application of the permeability test to on-site concrete

The results of Steps 1 and 2 were arranged in Figures 7 and 8 to examine the relationship between permeability property and the water-cement ratio, and the permeability of concrete exposed at a construction site was evaluated using these figures. The concrete information known before examination is as follows. The specimen was cast in ϕ 100×200 mm framework in a tunnel as shown in Figure 9. The upper end of the specimen was exposed on-site where it was located 30 meters from the tunnel entrance, and it was examined 30 days after casting. The specimen cement was blast-furnace slag cement. However, information such as the water-cement ratio and curing period was unknown, so these were predicted using the permeability test. Figure 10 shows the result of permeability test and an estimate of the water-cement ratio and curing period.

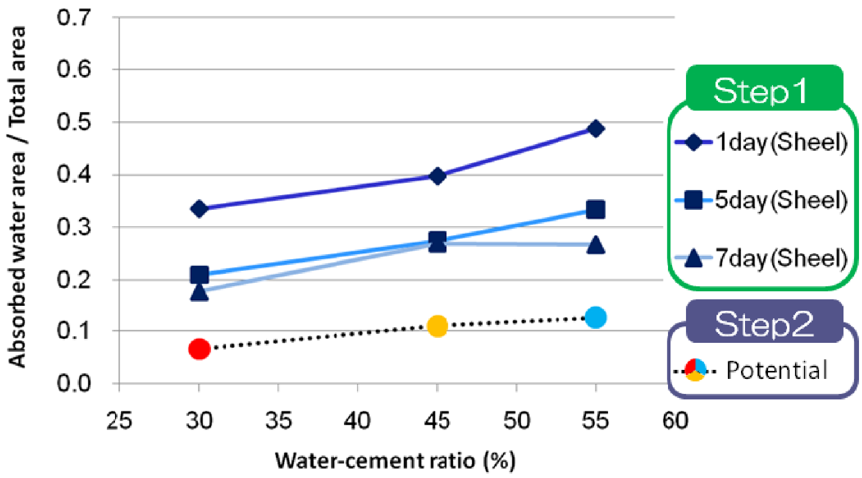

Figure 7: Relationship between permeability property and water-cement ratio (Portland cement : N)

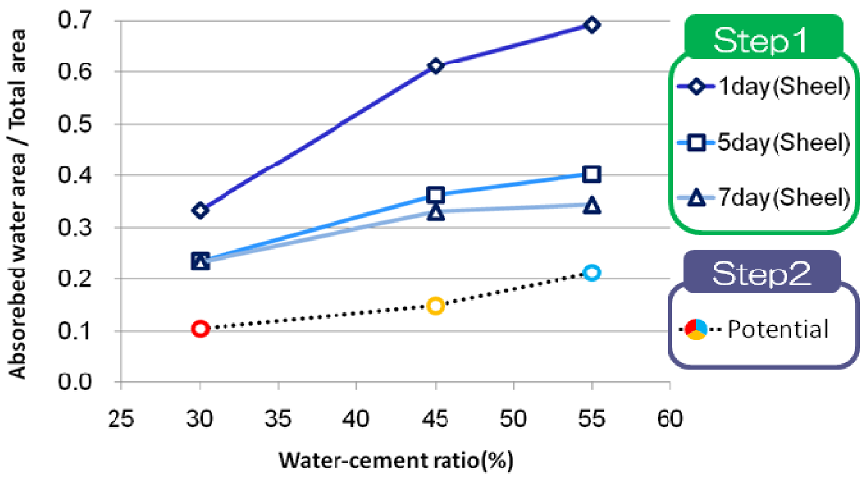

Figure 8: Relationship between permeability property and curing period (Blast-furnace slag cement : BB)

Firstly, the permeability property of internal concrete was compared with a test result of the potential (Step 2) and the water-cement ratio was estimated to be about 53% by the intersection point. Next, the permeability property of surface concrete was compared with the test result of Step 1, and the curing period was estimated to be between one and five days. After finishing the permeability test, the actual concrete information was received from the contractor. The water-cement ratio was 52.5% and curing period was two days, which demonstrates that this result showed that the permeability test can estimate these factors.

Figure 9: Tunnel where the specimen was cast

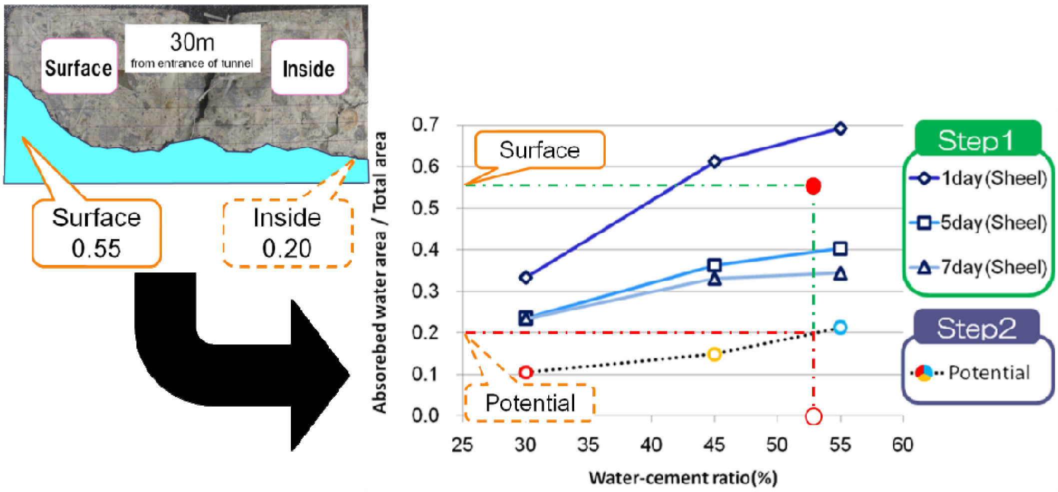

Figure 10: Result of permeability test and estimation method for water-cement ratio and curing period

5. CONCLUSION

This research aimed to establish a method for evaluating the permeability property of concrete structures, and also tried to understand the influence of durability factors. The conclusions of this study are as follows.

1. It was confirmed that the water-cement ratio and curing period had an influence on permeability property of surface and internal concrete.
2. It was clarified that the permeability property was greatly influenced by curing period. In this research, the original concrete properties could be estimated and the permeability property could be evaluated using the results from Steps

1 and 2, which examined the influence of curing time and difference between surface and internal properties. However, this estimation was only verified with one on-site specimen at this time.
3. In the future, it will be necessary to examine other types of cement and curing methods, and to increase the number of specimen in order to improve the precision of the method.

ACKNOWLEDGMENT

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REFERENCES

JSCE, 2007. Japan Standard Specifications for Concrete Structures, 122-124.
Y. Dan, T. Iyoda, Y. Ohtsuka, Y. Sagawa, H. Hamada, 2009, *The relationship between curing condition and durability on concrete using blast-furnace slag cement*, Journal of the Japan Society of Civil Engineers E, Vol.65 No.4, 431-441, Japan. (in Japanese)
H. Suzuki, S. Matsuzaki, T. Iyoda, 2010, *A durability test of the surface concrete using a core sample*, Journal of the Japan Society of Civil Engineers-kanto, Japan. (in Japanese)
S. Okazaki, T. Yagi, T. Kishi and T. Yajima, 2006, *Difference of sensitivity due to curing condition on strength and permeability*, Cement Science and Concrete Technology, NO.60, 227-234, Japan Cement Association. (In Japanese)
T. Iyoda, Y. Dan, Y. Sagawa, H. Hamada, 2008, *The effect of curing period on the durability of concrete usingBlast-furnace sag blended cement*, The 3rd ACF International Conference-ACF/VCA 2008

Effects of nutrient concentration on microbial cementation in Toyoura sand

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ABSTRACT

A new technique of ground improvement using microbial function has been recently proposed, as more eco-friendly technique than conventional one. Metabolic function of microbes produces carbon dioxide, which helps to generate calcium carbonate in soil. In this study, a series of trial test was conducted in order to evaluate the degree of soil cementation generated by those function in Toyoura sand specimens filled in a syringe. It was found that the cementation in soil can be roughly estimated by monitoring the change of the calcium ion concentration in the pore liquid. The concentration of nutrient affected the amount of precipitated calcium carbonate in sand.

Keywords: *Microorganisms, Urea , Calcium Carbonate*

1. INTRODUCTION

Some researchers reported that urease enzyme from "Bacillus Pasteurii" could be used to add cementation in sand (Dejong et al., 2006; Whiffin et al., 2010). In this study, a series of trial test was conducted in order to evaluate the degree of soil cementation generated by those microbial functions in Toyoura sand. Bacillus Pasteurii helps to precipitate calcium carbonate through the chemical process (Eq.1, 2, 3). Precipitated calcium carbonate on a soil grain and/or between soil particles seem to contribute to stiffen and strengthen the ground.

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-} \quad (1)$$

$$CO_2 + H_2O \rightarrow CO_3^{2-} + 2H^+ \quad (2)$$

$$Ca_2{+}{+}CO_3^{2}{-}\rightarrow CaCO_3\downarrow \quad (3)$$

2. MATERILS AND METHODS

Toyoura sand was filled in a 50ml plastic syringe to prepare a specimen of 29.5mm in diameter and 48mm in height. 17ml Nutrient solution which contains Calcium and carbon source, and 3ml Pasteurii ($2x10^6$ cells/ml) was put in a syringe in advance. Toyoura sand was pluviated through the solution to relative density of approximately 90 %.

In test series 1, two types of nutrient were used, Case A and B, as shown in Table 1. 20ml nutrient solution was poured into a specimen from top surface of a specimen and the same amount (20ml) was drained from the bottom at one day and two days later.

In test series 2, three kinds nutrient were used as shown in Table 2. Concentration of Case C is same as Case A (Table 1), Case D is twice, Case E is three times of that of Case C. Nutrient solution was supplied one day and two days after for only Case C.

For the evaluation of degree of cementation in a sand specimen, penetration tests were conducted. The penetration needle of 3mm diameter is shown in Fig.2. Penetration test was conducted at a rate of 10mm per minute up to a depth of 45mm. The calcium concentration and the pH of the pore liquid were also measured. After the test, enough amount of distilled water was flushed through the specimen in order to remove the remained nutrient solution and dry weight of specimen was measured. For all test cases, two specimens were tested for the same condition in order to check the repeatability of the test. In addition to that measurement, the strongly cemented portion from one of Case A specimen was observed by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) was performed using JEOL JSM-5600.

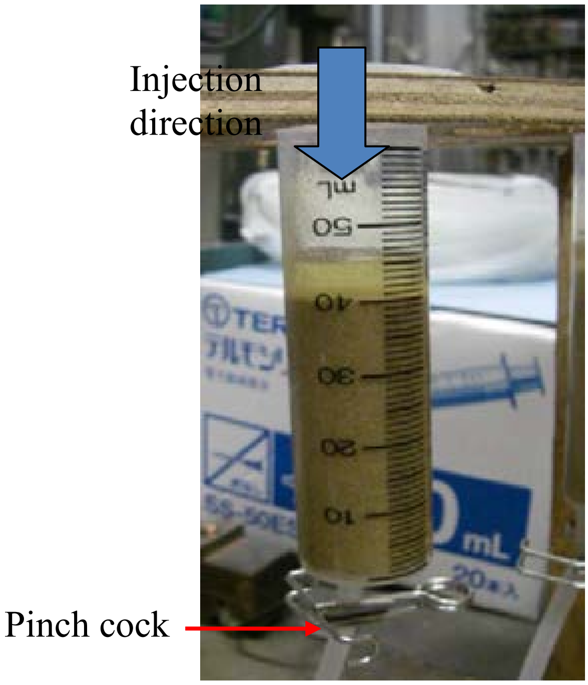


Figure.1: A specimen in a syringe

Figure.2 Penetration needle and tip shape

Table1: Composition of nutrient solution, Test1 (g/L)

Case	A	B
Bacto nutrient broth	3.5	0.35
Urea	35	3.5
$CaCl_2 \cdot 2H_2O$	82	8.2
NH_4Cl	12	1.2
$NaHCO_3$	2.4	0.24

Table2: Composition of nutrient solution, Test2 (g/L)

Case	C	D	E
Bacto nutrient broth	3	6	9
Urea	30	60	90
$CaCl_2 \cdot 2H_2O$	70	140	210
NH_4Cl	10	20	30
$NaHCO_3$	2	4	6

3. RESULTS AND DISCUSSION

3.1 TEST 1

Penetration resistance is shown in Figures 3 and 4. Comparing with dense/loose saturated Toyoura sand, it is clear that microbial cemented soil indicated larger resistance. The effectiveness of Pasteurii was therefore confirmed. Distinctive difference was shown between Case A and Case B due to different nutrient concentration. When three days passed, 3N was measured in Case B while 130 – 150N was measured in Case A.

Variation of Calcium concentration and pH is shown in Figure.5. Values of pH were 7.3 to 8.0 for both cases A and B, It is almost neutral that is appropriate for the calcium carbonate precipitation. Calcium concentration decreases greatly in Case A day by day. Case B was decreased from 1st day to the 2nd day. Afterwards, it was similar value.

The increment ratio of dry weight of the specimen before and after

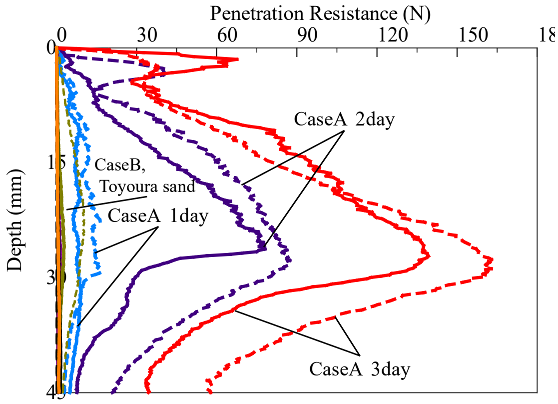


Figure.3: Penetration resistance in Case A

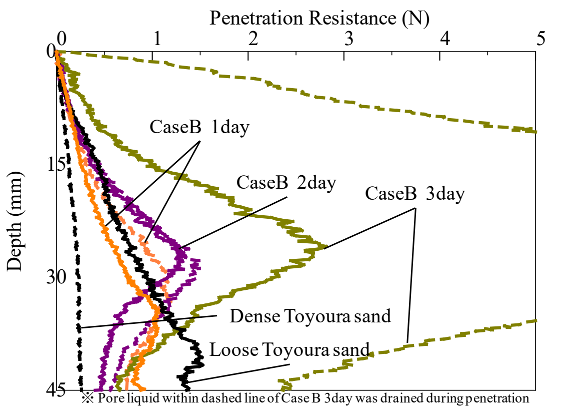


Figure.4: Penetration resistance in Case B

the test is plotted in Figure.6. Assuming that all remained nutrient were flushed in the washing process after experiment, weight increment is thought to be the calcium carbonate precipitation. The maximum value drawn in the short dashed line indicates the case in which all the added calcium ion precipitate as calcium carbonate. Plotted open symbol indicates calculated value based on the measured calcium ion in the pore liquid, assuming that a consumed calcium ion was precipitated as calcium carbonate. Weight increases day by day in Case A, and its increment is about 5% in three days. Case B was increased 0.5%. It almost corresponds to the ratio of the amount of calcium source given to the specimen. When calcium ion in pore liquid reacts completely, efficiency reaches 100%. Efficiency of Case A reaches around 80% with both measured and calculated weight in two days. Efficiency of Case B sometimes exceeded 100%, which indicates some errors involved in the measurement due to its low concentration.

Images of SEM and compositional mapping by EDS were provided in Figure.8. It is obvious that precipitated stuff adhere to the particle surface and pore in the part that has cemented strongly (Figure.8(a)) Furthermore, the result of compositional mapping shown in Figure.8 (b and c) indicates that precipitated stuffs mostly contains Calcium. Remarkable increase of penetration resistance in Test 1 was thought to be caused by particle bonding or friction increase due to precipitated calcium carbonate.

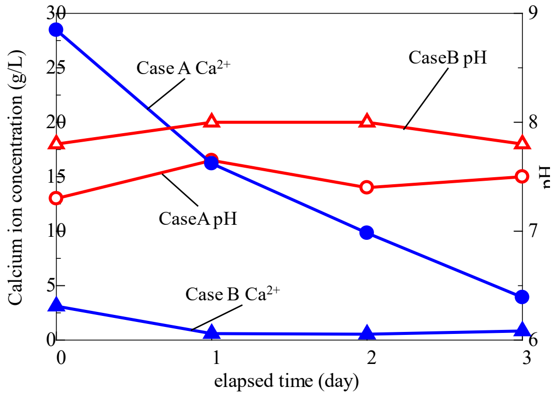


Figure.5: Calcium concentration and pH

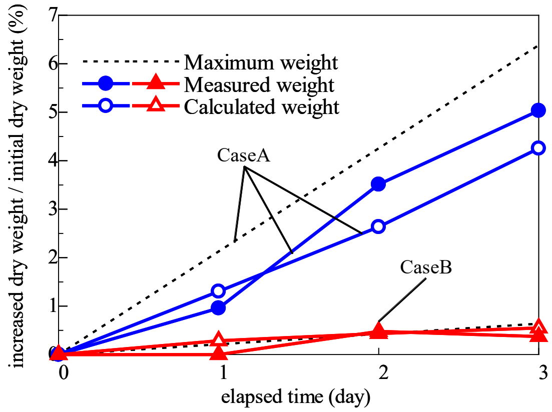


Figure.6: Increment ratio of dry weight of the specimen before and after the test

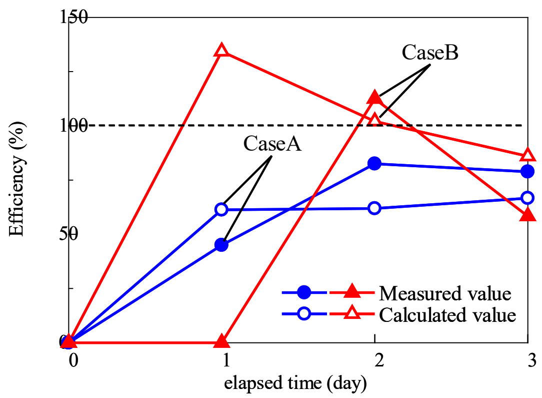
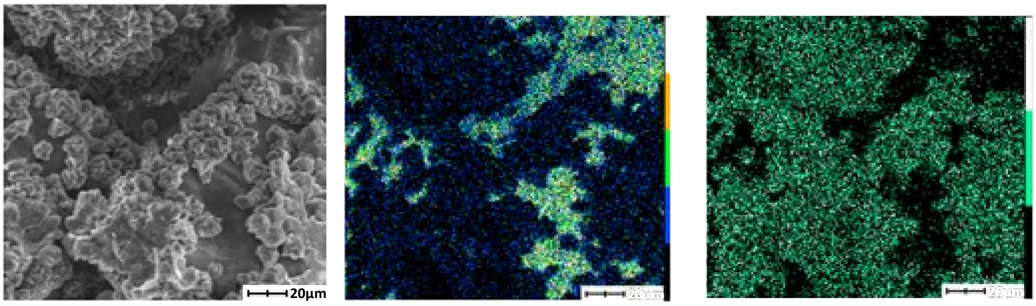


Figure.7: Efficiency of calcium carbonate precipitation



(a) (b) Ca (c) Si

Figure.8:Images of SEM and compositional mapping by EDS

3.2 Test 2

Penetration resistance is shown in Figure.9. Distinctive difference was also shown between Case C, D and E due to nutrient concentration. When three days passed, 10N was measured in Case E, 30N was measured in Case D while 150 – 200N was measured in Case C. Specimen that has the higher initial nutrient concentration indicates lower penetration resistance.

Variation of Calcium concentration and pH is shown in Figure.10. Lower values of pH were shown in case with higher concentration of nutrient. Substantial calcium ion was consumed day by day in Case C. In contrast, it was consumed 1/2, 1/3 of initial calcium ion in Case D ,E. The increment ratio of dry weight of the specimen before and after the test is plotted in Figure.11. Maximum value was calculated by same method as shown in Figure.6. A weight in Case C increases steadily. It reached 6% in three days, and got close to maximum value. Case D was increased 2%, Case E was increased 1%.

The efficiency of calcium carbonate precipitation is plotted in Figure.12. Efficiency of Case C reaches around 90% in three days. Case D was 60% Case E was 25%. The result of this experiment shows that higher initial concentration of nutrient prevent

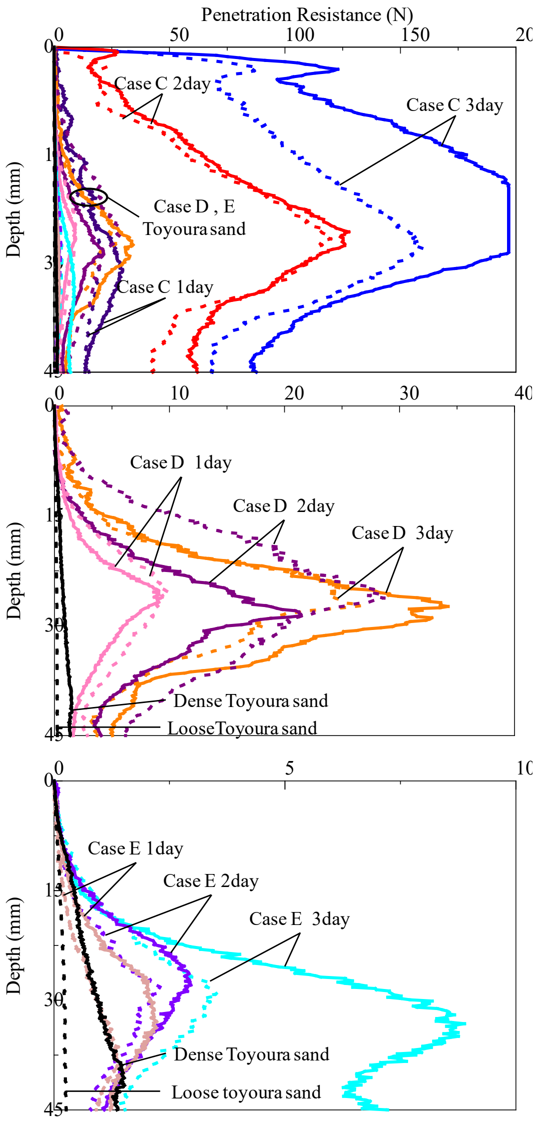


Figure.9: Penetration resistance in Case C(a), D(b), E(c)

chemical reaction. From the result of Test 2, it is concluded that inject nutrient by suitable concentration frequently is more reasonable.

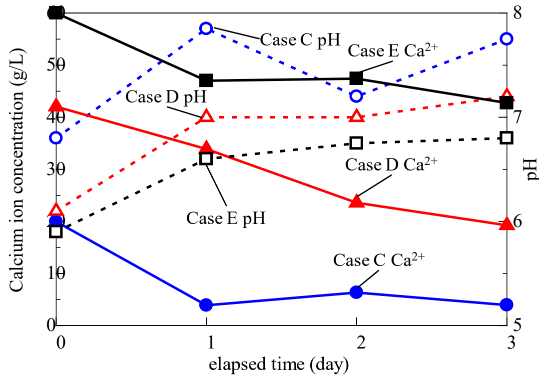


Figure.10: Calcium concentration and pH

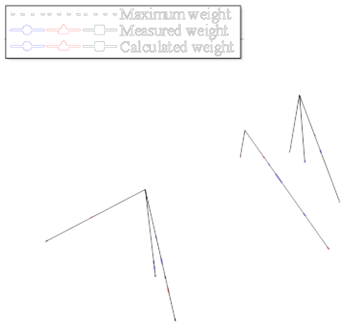


Figure.11: Increment ratio of dry weight of the specimen before and after

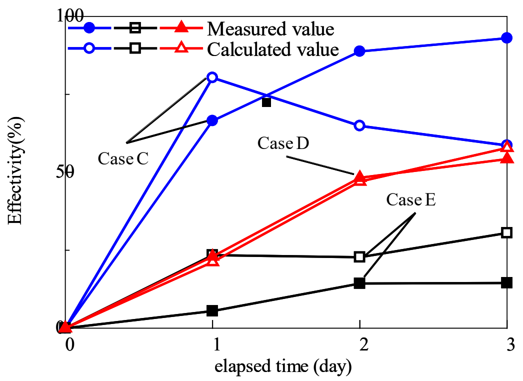


Figure.12: Efficiency of calcium carbonate precipitation

3.3 Relationship between calcium carbonate content and degree of cementation

Relationship between maximum penetration resistance and increment ratio of dry weight is presented in Figure.13. Specimen with a larger resistance exhibited heavier tendency. Amount of calcium carbonate and penetration resistance shows good agreement, which implies that consumption of calcium ion in the pore liquid can be reasonable indication to evaluate the degree of cementation.

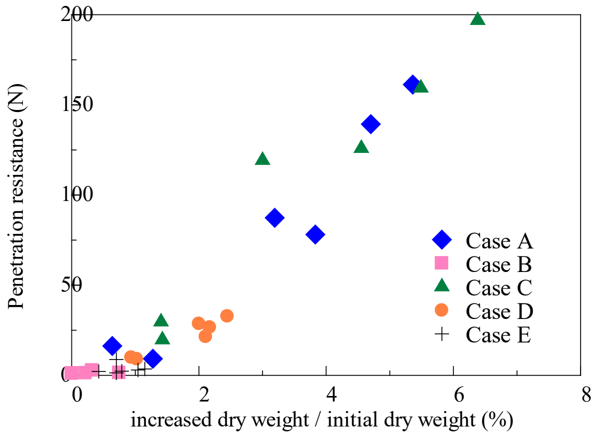


Figure.13: Relationship between maximum penetration resistance and increment ratio of dry weight

4.SUMMARY

The microbially cemented soil using urease enzyme from Bacillus Pasteurii exhibited success of cementation corresponding to nutrient concentration. The exsistence of a large amount of calcium carbonate on the Toyoura sand was also confirmed by the observation using SEM-EDS. When total amount of added calcium and nutrient is same, it is more effective that nutrient is injected separately and frequently.However, specimens in this test series show partial cementation. More effective nutrient concentration, injection interval and method for uniform cementation should be examined in the future.

REFERENCES

Jason T. DeJong, Fritzges, M.B. and Nüsslein, K.(2006), "*Microbially induced cementation to control sand response to undrained shear.*" Journal of Geotechnical and Geoenvironmental Engineering, Vol.132, No.11, pp.1381-1392.

Marien P. Harkes, Van Paassen L.A., Booster J.L., Whiffin V.S., Van Loosdrecht M.C.M. (2010), " Fixation and distribution of bacterial activity in sand to induce carbonate precipitation for ground reinforcement." Ecological Engineering, Vol.36, Issue2, pp.112-117.

Fundamental study of permeability change around buried structures in sandy ground

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ABSTRACT

Many cave-in accidents occur and sometimes injure people. Expansion of an underground cavity and loosening causes cave-in accidents. Some accidents supposed to be caused by soil outflow from broken parts of sewer pipes in shallow ground. However, the mechanism of a cavity and loosening generation is not clear. It is so hard to prevent cave-in accidents before a cavity and loosening expand to the ground surface.
Recent researches show that a boundary between a basement structures and the ground may be one of the important factors of causing cave-in accidents. It is supposed that water pathway expands through the gaps between a buried structure and the ground due to a change of the water level. Then water pathway causes soil drainage which makes expansion of a cavity and loosening.
In order to study the effect of permeability at the boundary, constant head permeability test which has the contact plane between the ground and the acrylic cylinder was conducted.

Keywords: *cave-in, water pathway, permeability test, buried structure,*

1. INTRODUCTION

Many ground cavities and loosening are found in the ground close to underground structures nowadays. It is a serious problem in urban cities because cavities and loosening sometimes leads to cave-in accidents which injure people. One factor of expansion of cavities is distinct spots of soil outflow like broken parts of sewer pipes, as shown in Figure 1. Kuwano et al. (2006) conducted model test simulating how a cavity is generated due to the broken parts of sewer pipes. However, specific spots of soil outflow are seldom found near to cavities. The reason why cavities and loosening are generated and expanded around the underground structures without visible spots of soil outflow is not clear. In this research, it is suggested that boundary between the ground and buried structures has water pathway which cause soil outflow. Figure 2 schematically represents such kind of situation. This paper attempts to investigate permeability changes due to the existence of gaps between the basement structures and the ground. In the concrete, constant head permeability test which insert an acrylic cylinder was conducted.

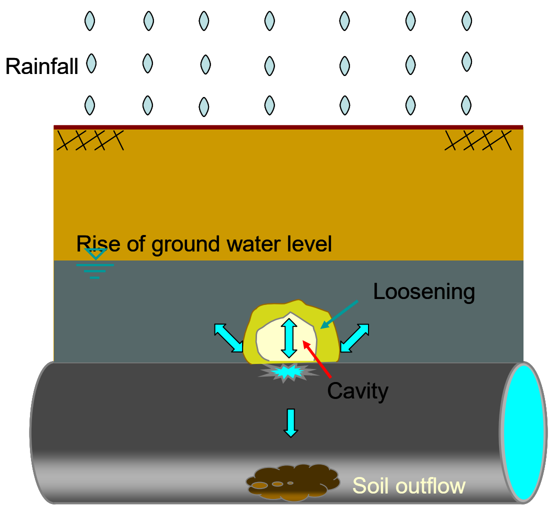

Figure 1: A Cavity and loosening formed above the defective buried pipes

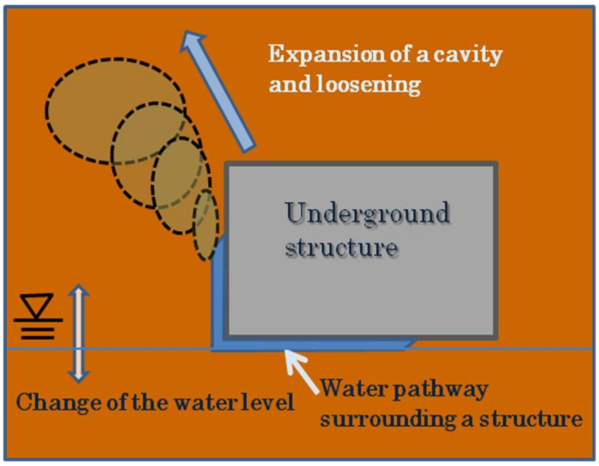

Figure 2: Situation of expansion of a cavity and loosening around a buried structure

2. TEST APPRATUS AND PROCEDURE

Concept of our experiments is shown in Figure 3. Apparatus of constant head permeability test is adopted. A photograph of the test apparatus is shown in Figure 4. Diameter of the soil chamber is 10cm. Hime gravel is put as a filter above the tested material. Acrylic cylinder is placed at the center of this soil chamber and soil is compacted by Air Pluviation, AP. Figure 5 represents the situation how to prepare the soil chamber. The boundary between acrylic cylinder and the soil are supposed to be the boundary between buried structures and the ground.

After finishing preparation of soil chamber, soil chamber is inserted into a water chamber and water is poured into the soil chamber. Each water level of the soil chamber and the water chamber is constant during the permeability test. The amount of penetrated water in 180 second, head difference between soil chamber & water chamber and water temperature were measured. Calculated coefficient of permeability is corrected as that at 15 degrees Celsius.

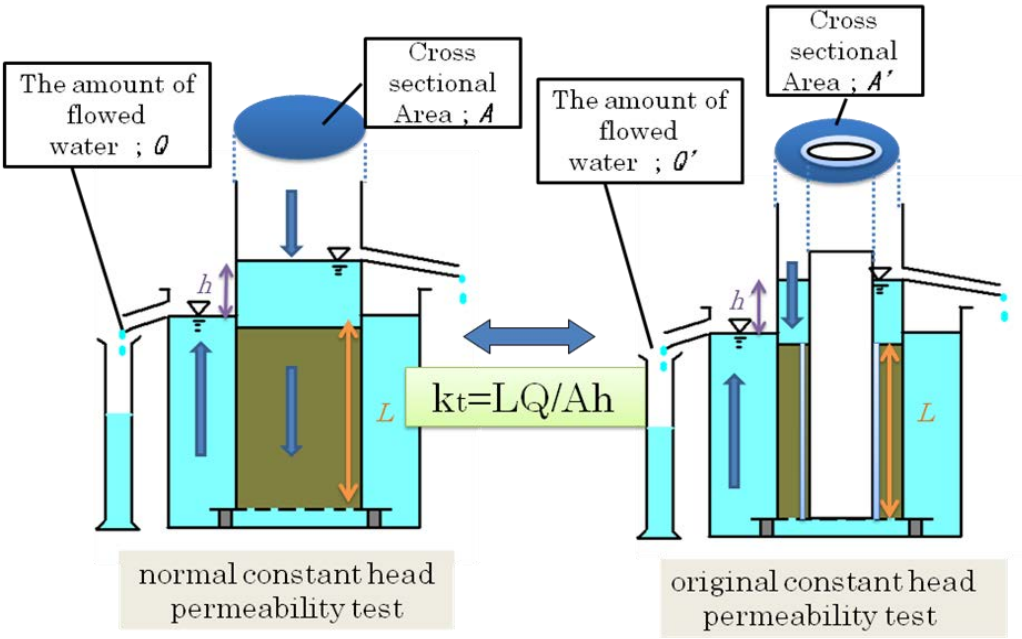

Figure 3: Concept of the permeability test placing a cylinder

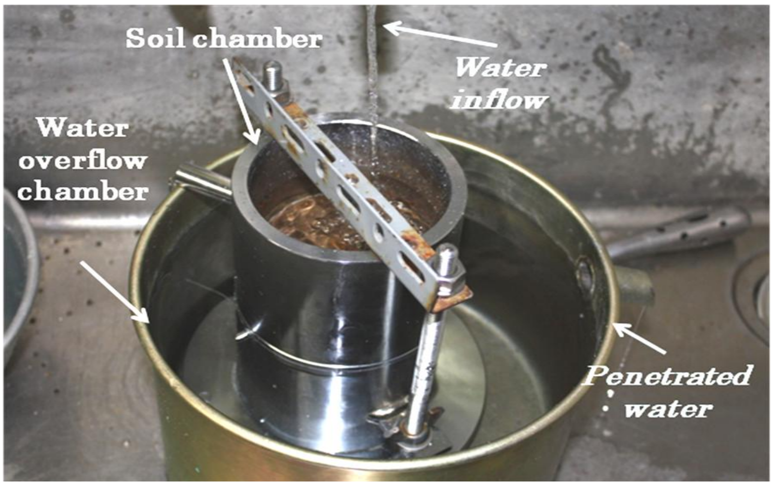

Figure 4: Situation of conducting permeability test

Figure 5: Preparation of the soil chamber

3. TEST CONDITIONS

Test conditions are shown in Table 1. Tested materials, density, diameter of an acrylic cylinder, surface form of a cylinder were changed. Three sandy materials are used– Toyoura sand, Silica sand no.5 and Silica sand no.8. Figure 6 represents the particle size distribution of three materials. Both Toyoura sand and Silica sand no.5 are clean uniform sand, but average particle size of Silica sand no.5 is larger than that of Toyoura sand and Silica sand no.8. Silica sand no.8 contains fines around 15%. Surface form of an acrylic cylinder was changed by putting panels made by plastic tapes as shown in Figure 7. Size of each panel is about 10mm × 15mm and thickness of the panel is about 0.2mm. These panels cause surface of an acrylic cylinder uneven. In this research, this uneven cylinder is named as "rough cylinder" and normal cylinder is named as "smooth cylinder".

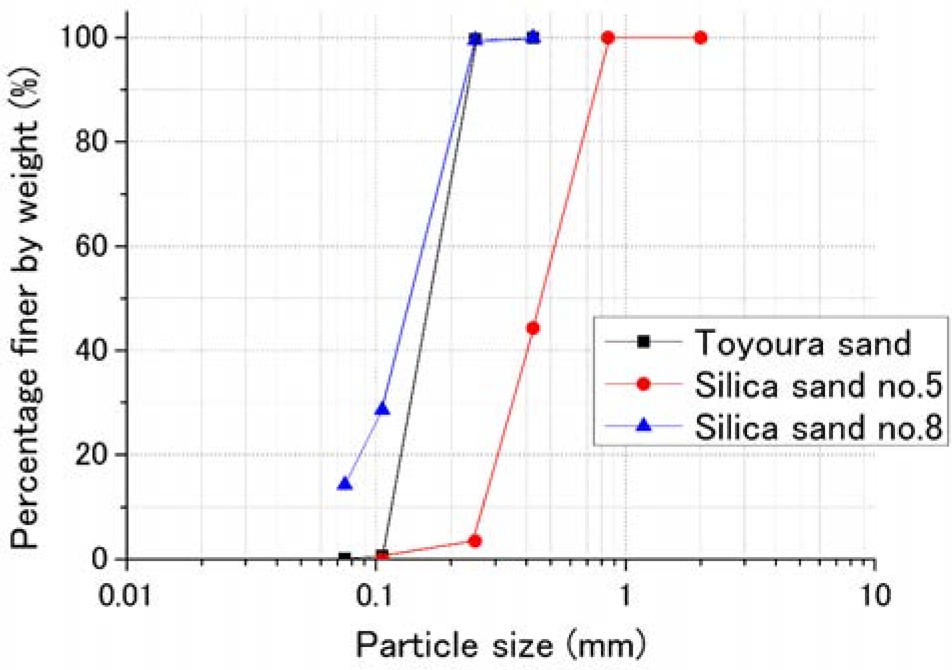

Figure 6: Particle size distributions of three materials

Table 1: Test conditions

Material	State of a cylinder (diameter, rough or smooth)	Relative Density (%)
Toyoura sand	No cylinder	30
Toyoura sand	No cylinder	39
Toyoura sand	No cylinder	79
Toyoura sand	5cm smooth	30
Toyoura sand	5cm smooth	78
Toyoura sand	5cm rough	36
Toyoura sand	5cm rough	71
Toyoura sand	7cm smooth	34
Toyoura sand	7cm smooth	77
Toyoura sand	7cm rough	34.5
Toyoura sand	7cm rough	70.5
Silica sand no.5	No cylinder	72
Silica sand no.5	5cm smooth	74
Silica sand no.5	5cm rough	74
Silica sand no.5	7cm smooth	72
Silica sand no.5	7cm rough	62
Silica sand no.8	No cylinder	40
Silica sand no.8	No cylinder	70
Silica sand no.8	5cm smooth	34
Silica sand no.8	5cm smooth	72
Silica sand no.8	5cm rough	34
Silica sand no.8	5cm rough	71.5

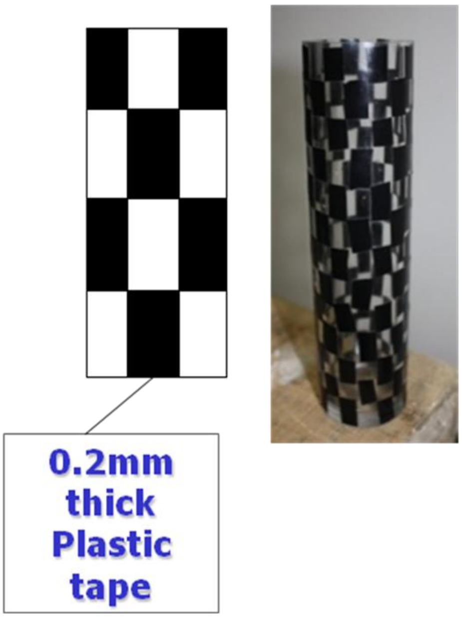

Figure 7: Appearance of ” rough cylinder”

4. TEST RESULTS

4.1 Test results of Toyoura sand

Relationship between relative density and permeability coefficient is shown in Figure 8. Square symbols dots represent the result without a cylinder, which is regarded as result of normal constant head permeability test. Figure 8 refers that smooth (normal) cylinder doesn't have much influence on permeability. On the other hand, rough cylinder (uneven surface) cause increasing of permeability and diameter of a cylinder is not so important for permeability in loose sand. Permeability of a cylinder with 7cm diameter is larger than that of a cylinder with 5cm diameter in dense sand. Conditions of rising permeability are different between loose sand and dense sand.

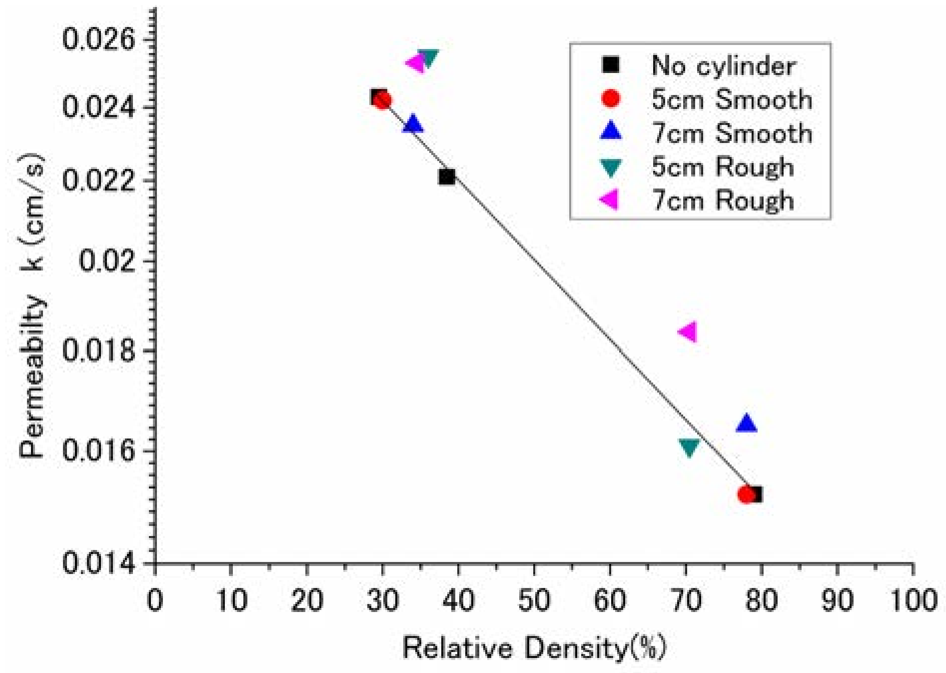

Figure 8: Permeability coefficient of Toyoura sand

4.2 Test results of Silica sand no.5

Results of permeability test of Silica sand no.5 are shown in Figure 9. Figure 9 indicates that cylinder with 5cm diameter makes permeability increase. It can be suggested that roughness of a cylinder with 5cm diameter isn't significant for permeability because permeability coefficient of rough cylinder is similar to that of smooth cylinder. In contrast, the result of a cylinder with 7cm is different from the result of a cylinder with 5cm diameters. Rough cylinder doesn't cause increasing of permeability.

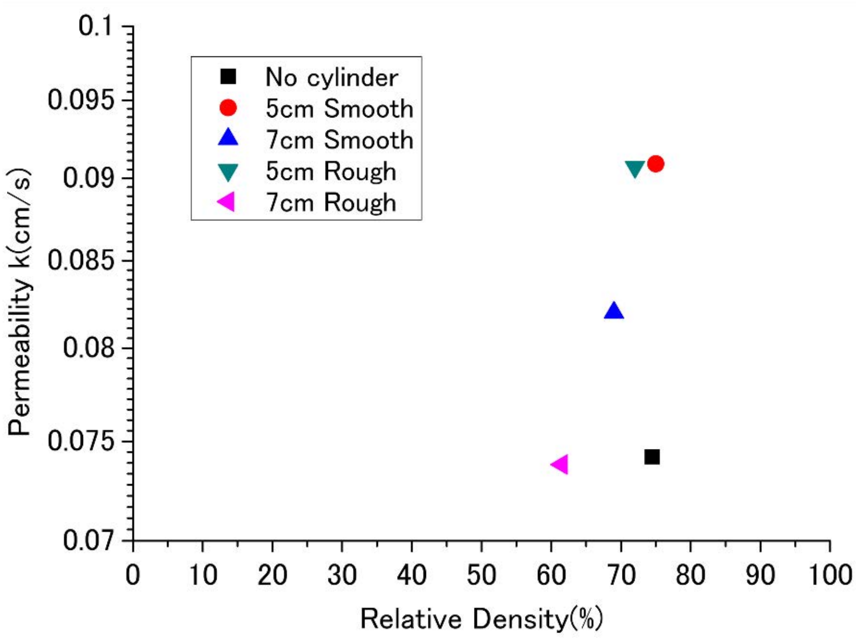

Figure 9: Permeability coefficient of Silica sand no.5

4.3 Test results of Silica sand no.8

Results of permeability coefficient of Silica sand no.8 are shown in Figure 10. Permeability test placing a cylinder with 7cm diameter wasn't conducted in Silica sand no.8. It is proposed from Figure 10 that smooth cylinder let permeability increase in loose sand, and rough cylinder let permeability increase in dense sand. This tendency can be also stated that permeability change between loose sand and dense sand is largest with smooth cylinder, and smallest with rough cylinder.

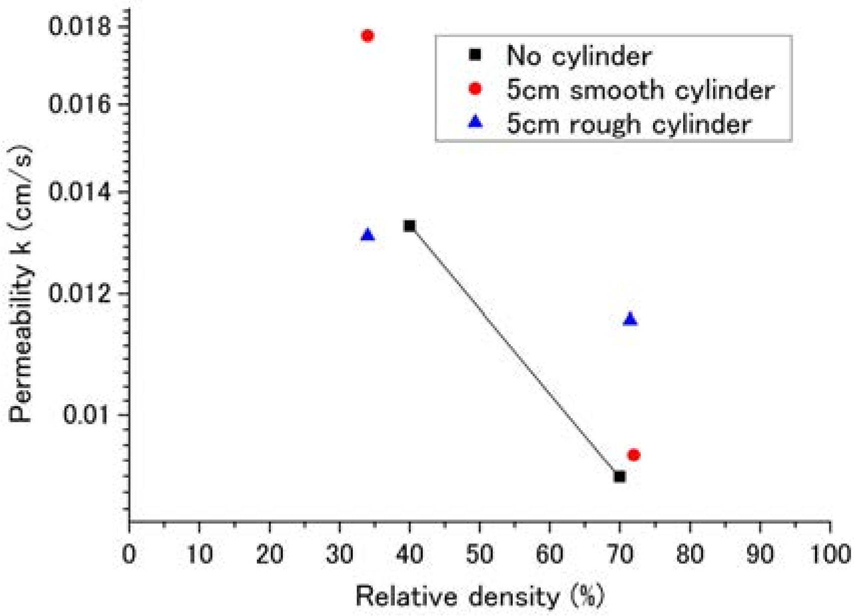

Figure 10: Permeability coefficient of Silica sand no.8

4.4 Influence on the direction of surface unevenness of a cylinder

Referring to the results of Toyoura sand (4.1), it can be suggested that surface uneven of a cylinder (rough cylinder) makes permeability increase especially in loose sand. To investigate which direction of unevenness is most critical to increase permeability coefficient, three kinds of rough cylinder were installed. Each of three cylinders has different direction of roughness – normal, horizontal and vertical. These cylinders are prepared by putting plastic panel (0.2mm thickness) as Figure 11 is shown. Normal rough cylinder is same as rough cylinder it has been defined in previous chapters. Test procedure was same as previous one (referring to chapter 2). Table 2 represents test conditions.

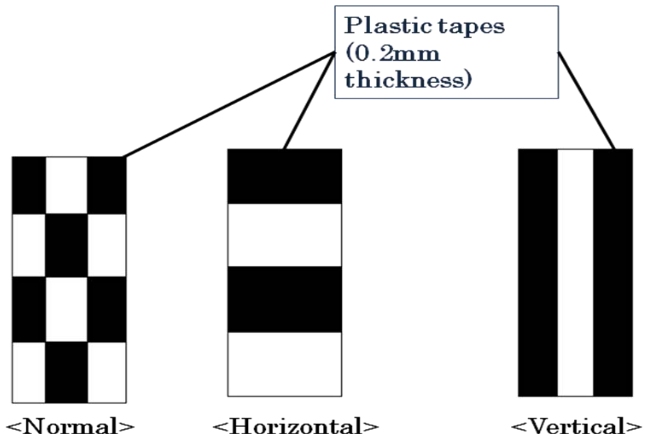

Figure 11: Three different types of rough cylinder

Table 2: Test Conditions

Material	State of a cylinder (diameter, *direction of roughness*)	Relative Density (%)
Toyoura sand	5cm vertical rough	30
Toyoura sand	5cm horizontal rough	39

Permeability coefficients of three rough cylinders are shown in Figure 12. Figure 12 is also plotted results of other conditions of Toyoura sand, which has been already explained in 4.1. Figure12 suggested that horizontal direction of roughness is the most sighnificant for increasing permeability.

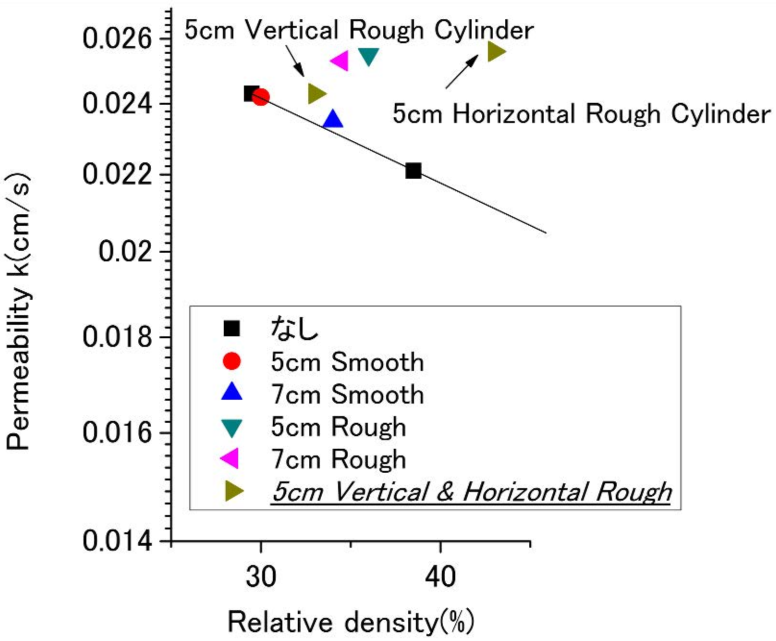

Figure 12: Permeability coefficient of vertical & horizontal rough cylinder

5. CONCLUSIONS

If permeability increases due to installing a cylinder, it can be proposed that boundary between a cylinder and soil cause water pathway. In this research, permeability putting a cylinder is often higher than normal permeability especially in loose sand. This result suggested that loose sand has larger gaps and makes water pathway easier than dense sand. Direction of unevenness is also important for making water pathway. Horizontal roughness (Referring to 4.4), which is regarded as vertical uneven direction to water penetration, has some influence on causing water pathway. Why material difference affects permeability is not clear, but particle size or fines may have some effect of forming gaps. This research suggests existence of water pathway between buried structures and the ground in particular conditions.

REFERENCES

Kuwano, R, Yamauchi, K., Horii, T. and Kohashi, H. 2006. *Defects of sewer pipes causing cave-in's in the road,* Proc. of 6th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia, Phuket, November 2006.

Mechanical properties and seismic behavior of soil walls using rammed earth technique

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ABSTRACT

Rammed earth is a traditional construction technique to build soil structures by compacting clay, sand, gravel and, if needed, cementitious materials. The rammed earth walls are frequently seen in historic heritages in Japan. Furthermore, the rammed earth walls have been also applied to modern architecture due to their advantages of using natural soil materials in recent years. However, the mechanical properties and the seismic resistance of rammed earth walls have not been fully investigated. In this study, therefore, the shear and tensile properties of rammed earth materials made of a mixture of soil, lime and water, were evaluated by conducting a series of compaction test, unconfined compression test, unconfined tension test and drained triaxial test. Moreover a finite element analysis based on an elasto-plastic model that can describe the mechanical properties of rammed earth material was conducted in order to clarify the seismic behavior of rammed earth walls.

Keywords: Rammed earth, soil walls, lime mixed soil, laboratory test, FEM

1. INTRODUCTION

Rammed earth is a traditional architectural technique, and soil walls using this technique are frequently seen in historical heritages. The soil walls surrounding Horyu-ji temple, Nara (Fig. 1a), Taikou-bei in Sanju-sangen-do temple, Kyoto (Fig. 1b) and Ohneri-bei in Nishinomiya shrine, Hyogo are famous rammed earth walls in Japan. Effective conservation and repair methods need to be established in order to pass on these cultural heritages to next generations.

In recent years, the rammed earth is getting a rising interest in construction projects of individual housing, since it is with some advantages which include temperature and humidity control performance, fire resistance performance, potential for recycling and low negative impact on the environment of natural soil materials (Hall, 2007; Morel et al., 2001). However, mechanical properties and seismic behavior of rammed earth walls have not been clarified sufficiently.

Evaluation of seismic safety of a rammed earth wall is required in conducting an appropriate design of a newly built wall in earthquakes-prove countries like Japan.

In this study, seismic behavior of a rammed earth wall was evaluated by a finite element analysis. It was carried out employing an elasto-plastic model that can describe the mechanical properties of a lime-mixed soil which is often used as a rammed earth material in Japan. In addition, the mechanical properties of lime-mixed soil were obtained on some laboratory tests.

Figure 1: a) Rammed earth walls surrounding Horyu-ji temple, Nara and b) Taikou-bei in Sanju-sangen-do temple, Kyoto, Japan.

2. EVALUATION OF MECHANICAL PROPERTIES

In order to obtain mechanical properties of a rammed earth material, unconfined compression tests, triaxial compression tests and unconfined tension tests were carried out.

2.1 Specimen of lime-mixed soil

As a rammed earth wall material, a lime-mixed soil that was composed of silty sand, poorly graded sand and quicklime was prepared. Mixing proportion is shown in Table 1. Specimens were prepared by compacting the material in layers of 1 cm-thick under the optimum water content. The compacting energy was 2700 kJ/m^3 which is equivalent to the modified Proctor test. The shape of specimens for unconfined compression tests and triaxial compression tests is a cylinder with a diameter of 50 mm and a height of 100 mm. The shape of specimens for unconfined tension tests is a dog-bone with a maximum diameter of 50 mm and a height of 140 mm and the diameter at the middle height is trimmed down to 45 mm.

Specimens after curing for 28 days were used for all the tests. All specimens were cured in air without sealing under atmospheric pressure and room temperature.

Table 1: Mixing proportions to prepare tested material

	Volume ratio	Weight in percentage (%)
Silty sand	4	53.8
Poorly graded sand	0.5	8.8
Quicklime	1	14.2
Water	2	23.2

2.2 Test result and discussion

The axial strain rate of unconfined compression and triaxial compression tests was set to 1 %/min, and that of unconfined tension test was 0.01 %/min. The triaxial compression tests were carried out under drained condition with a confining pressure of 20 kPa, 50 kPa and 100 kPa.

The results of unconfined compression and tension tests are compared in Fig. 2 in terms of the stress-strain relations. The average values of the mechanical properties are shown in Table 2. The stress-strain relationships in tension test show that stress reduces sharply after the peak strength. The tensile strength values are very low and represent only 5% of compressive strength ones. The tensile strength of lime-mixed soil are lower than those found by Koseki et al. (2008) on cement-treated sands (mixing proportions for cement/water/sand being similar to those of lime/water/soil) after a curing period of 7 days, which ranged from 20 to 30% of the unconfined compression strength for a shorter curing period. For a curing period in this study four times higher than that of the cement-treated sands, the tensile strength for the lime-treated soil is three to six times lower.

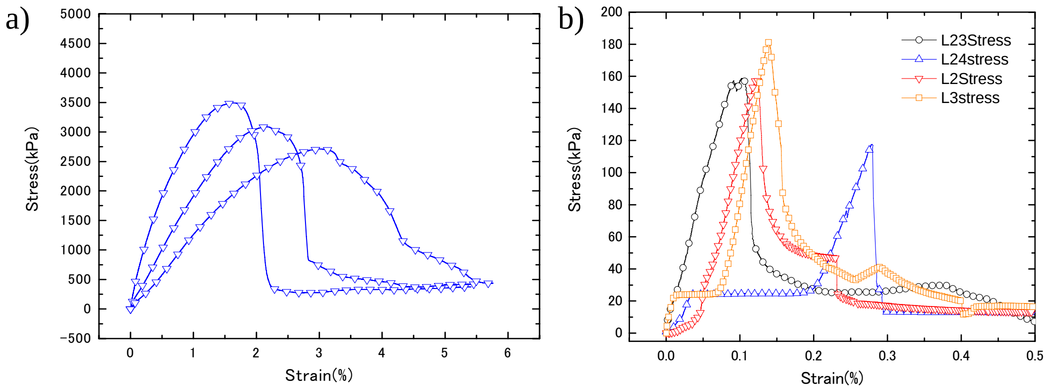


Figure 2: Stress strain relationships of a) unconfined compression test and b) unconfined tension test. (The axial strain was measured with an external transducer, respectively.)

The cohesion and the internal friction angle were obtained by drawing the Mohr circle at the peak stress state of the results of the triaxial compression tests, as can be seen in Table 2. In addition, the secant modulus, E_{50} for the unconfined compression tests, unconfined tension tests and triaxial compression tests at a confining pressure of 20 kPa are shown in Table 2. These values were used to decide a numerical elasto-plastic model of lime-mixed soil for a finite element analysis in this study.

Table 2: The results of mechanical properties of lime-mixed soil

Unconfined compression test	Compression strength (kPa)	3098
	E_{50} (MPa)	240
Unconfined tension test	Tensile strength (kPa)	154
	E_{50} (MPa)	173
Triaxial compression test	Peack angle of internal friction, ϕ (°)	35.3
	Cohesion, c (kPa)	983
	E_{50} (MPa)	656

3. EVALUATION OF SEISMIC BEHAVIOR

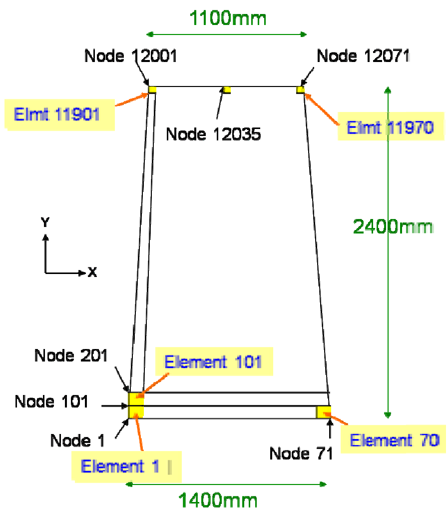
The seismic behavior of rammed earth wall section is investigated using a two-dimensional finite element analysis, while incorporating experimentally obtained properties of the lime-mixed soil in the unconfined compression tests, unconfined tension tests and triaxial compression tests.

3.1 Finite element mesh and seismic wave

The prototype model analyzed is shown in Fig. 3. It reflects the cross section of a soil wall in a certain temple. The height of the wall is 2400 mm, the top width 1100 mm and the bottom width 1400 mm. It is composed of 8400 elements of around 20*20 mm^2 and 8591 nodes.

The boundary at the base row is fixed in the horizontal and vertical directions. A damper was added at this boundary so that the seismic waves are not trapped in the soil wall and can be dissipated into the ground. Roof load was modeled by placing a beam element at the top of the wall, with a self weight that is equivalent to an intensity of 3.31 kPa using a small elastic modulus (E = 10 MPa).

The N-S component of the recorded earthquake motion at Kobe JMA (Japan Meteorological Agency) station during the 1995 Hyogoken-Nanbu earthquake was used as the base input motion (Fig. 4). This input motion was applied in the horizontal direction and the duration of the excitation was 20 seconds. The input motion was modified by rescaling the maximum acceleration from 200 gal to 1000 gal.



Figuer 3: Prototype model of a rammed earth wall

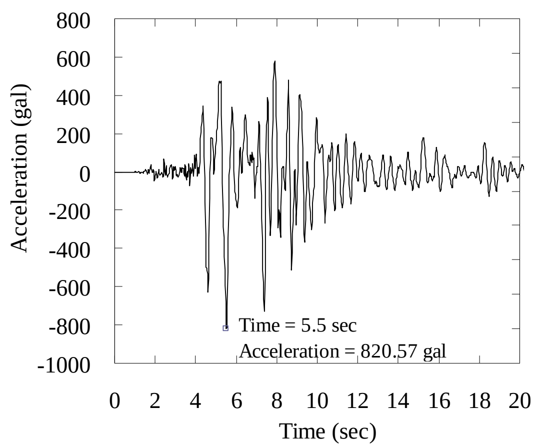


Figure 4: Original input motion of JMA-Kobe wave

3.2 Constitutive model and parameters of a soil wall material

An elasto-plastic model developed by Namikawa and Mihira (2007) that can describe the non-linear shear and tensile behaviors of cement-treated soils was used in this study. Two failure criteria are employed to express tensile and shear failure characteristics observed in the experimental results of the cement-treated sands. It can model strain-hardening and strain-softening responses in both failure modes. In the strain softening rules, the smeared crack concept is used and a characteristic length is employed to avoid the issue of mesh-size dependency. The details of the model are not explained in this paper and can be found in Namikawa and Mihira (2007). This model was successfully used to simulate the tensile and shear behavior of cement-treated sand in the laboratory tests (Namikawa and Koseki, 2007).

The elastic modulus, E, the tensile strength, T_f, the angle of internal friction, ϕ and cohesion, c were deduced based on the laboratory tests results (Table 2), as can be seen Table 3. Elastic modulus and tensile strength were assigned as 200 MPa and 150 kPa, respectively, in a conservative approach. When necessary, T_f was modified from 150 kPa to 300 kPa in order to obtain information about the influence of tensile strength.

The parameters listed in the second part of Table 3 are assigned based on relevant references (Namikawa and Koseki, 2006; Namikawa and Mihira, 2007; Koseki et al., 2008). The hardening parameters, a and e_y are linked the strain-hardening response of cement or lime-treated soils. The fracture energy, G_f is a parameter dominating the tensile strain-softening behavior. The parameters e_r and D_c are related to the shear fracture energy and to the dilation during the shear strain softening process, respectively. t_{s0} is related to the size of strain localization zone and is assumed to be 0.6 mm, and l_c is determined from the mesh size, i.e. around 20 mm.

Viscous Rayleigh damping was employed as the damping. C= αM+ βK where M, C and K are the mass, damping and stiffness matrices, and α and β are the damping parameters. As the damping matrix C functions depend on the frequency, these parameters were obtained by an eigen value analysis while assuming the modal damping factor of the Rayleigh damper $h_r = 1/2\ (\alpha / w_r + \beta w_r) = 0.02$ at the first and second dominant frequencies of the wall (f_1 =11 Hz and f_2 =37 Hz).

Table 3: The results of mechanical properties of lime-mixed soil

Experimentally deduced parameters		
Elastic modulus	E (MPa)	200
Tensile strength	T_f (kPa)	150
Angle of internal friction	ϕ (°)	35.3
Cohesion	c (kPa)	983
Density	ρ (g/cm^3)	1.70
Assumed parameters		
Poisson's ratio	ν	0.33
Hardening parameter	a	1.05
Hardening parameter	e_y	0.0002
Fracture energy	G_f (N/m)	37.5
Softening parameter	e_r	0.40
Dilatancy coefficient	D_c	-0.4
Localization size	t_{s0} (mm)	0.6
Characteristic length	l_c (mm)	20.0
Damping coefficients	α	2.10
	β	0.000133

4. RESULT OF SEISMIC RESPONSE ANALYSIS

By inputting the properties presented above, the walls failed: numerical analysis could not be successfully completed as the number of iterations increased significantly, where many elements failed for the duration of the strong motion. Therefore the tensile strength T_f and the maximum acceleration A_{max} of the input motion were varied in order to evaluate the seismic response of the soil wall.

4.1 Stress state in the soil wall

The maximum values of the minor principal stress in tension, σ_3, mobilized at the left bottom corner of the wall (Element 1, Fig. 3) are plotted versus the maximum acceleration A_{max} in Figure 5. In the case with T_f of 150 kPa, the relationship between $|\sigma_3|$ and A_{max} is linear when $|\sigma_3|$ is smaller than 150 kPa. When A_{max} exceeded 525 gal, $|\sigma_3|$ does not increase even if A_{max} increases. When A_{max} was larger than 650 gal, the analysis could not be completed. In other words, partial failure occurred when A_{max} is between 525 gal and 650 gal, and it was followed by overall failure that took place when A_{max} was larger than 650 gal. A similar trend could be observed in other cases where the value of T_f is 200 kPa, 250 kPa and 300 kPa.

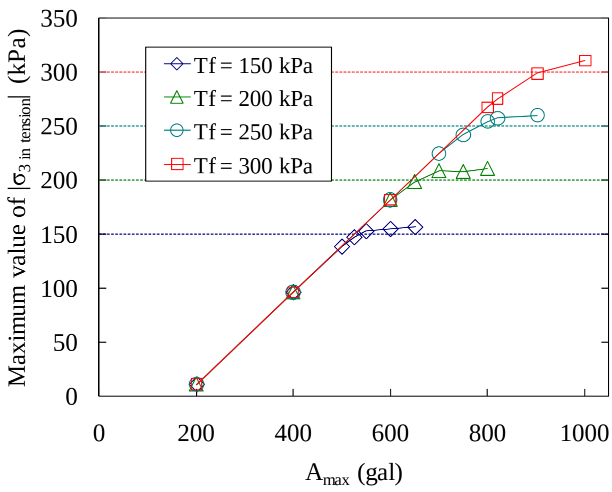


Figure 5: Maximum values of minor principal stress in tension

The time histories of the minor principal stress and the maximum shear stress, τ_{max} in the case with T_f = 150 kPa and A_{max} = 650 gal are shown in Fig. 6. The distributions of σ_3 and τ_{max} when A_{max} occurs are shown in Fig. 7. The maximum value of τ_{max} is mobilized at the right bottom corner of the wall and its value is 153.4 kPa. The shear failure could not be observed because the maximum value of τ_{max} was smaller than the cohesion of 983 kPa. On the other hand, the maximum value of σ_3 in tension is mobilized at the left bottom corner of the wall, and its value is -156.5 kPa. Tensile failure occurred at this element because $|\sigma_3|$ exceeded the tensile strength of 150 kPa. Therefore, not the shear failure but the tensile failure would occurs in the soil wall in the event of an earthquake.

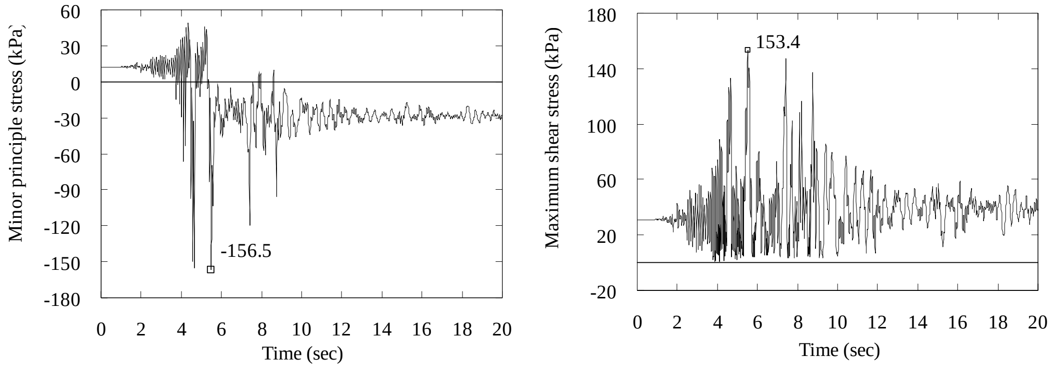


Figure 6: Time histories of the minor principal stress and the maximum shear stress (T_f and A_{max} are 150 kPa and 650 gal, respectively.)

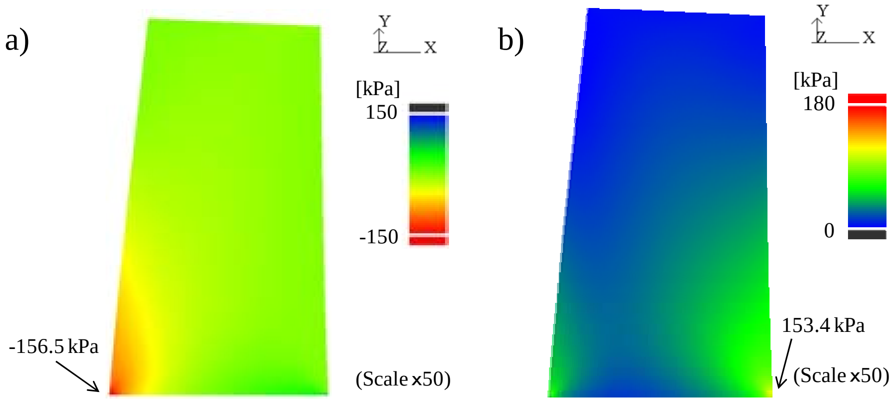


Figure 7: Distribution of a) the minor principal stress and b) the maximum shear stress (Time is 5.5 sec. T_f and A_{max} are 150 kPa and 650 gal, respectively.)

4.2 Displacement of the soil wall

The maximum values of the vertical and the horizontal displacement at the left top corner of the soil wall (Node 12001, Fig. 3) are plotted versus the maximum acceleration A_{max} in Figure 8. The displacements are very small compared to the dimensions of the wall. Moreover, they exhibit a linear relationship with the maximum acceleration, even when partial failure occurs. These observations suggest that the wall response is more like a rigid body.

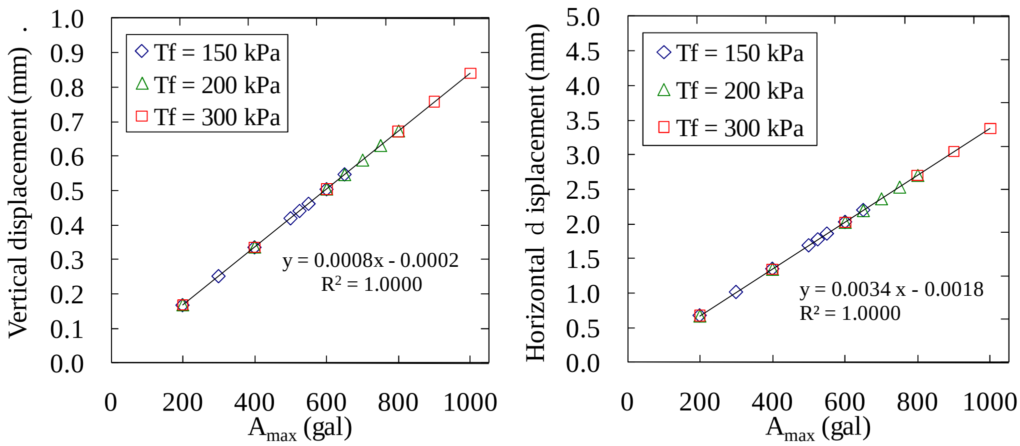


Figure 8: The maximum values of the vertical and the horizontal displacement in function of A_{max}

The time histories of the vertical and the horizontal displacement in the case with T_f = 150 kPa and A_{max} = 650 gal are shown in Fig. 9. The distributions of the vertical and the horizontal displacement when A_{max} occurs are shown in Fig. 10. The maximum vertical displacement and the maximum horizontal displacement are 0.55 mm and 2.20 mm at 5.5 sec, respectively. The distributions of both displacements show rocking motion of the soil wall. The risk of overbalancing of the soil wall is increased when the rocking motion occurs severely as the result of the tensile failure at the bottom of the wall. In order to restrain the large horizontal displacement, tensile strength should be evaluated correctly, and the tensile failure should be prevented.

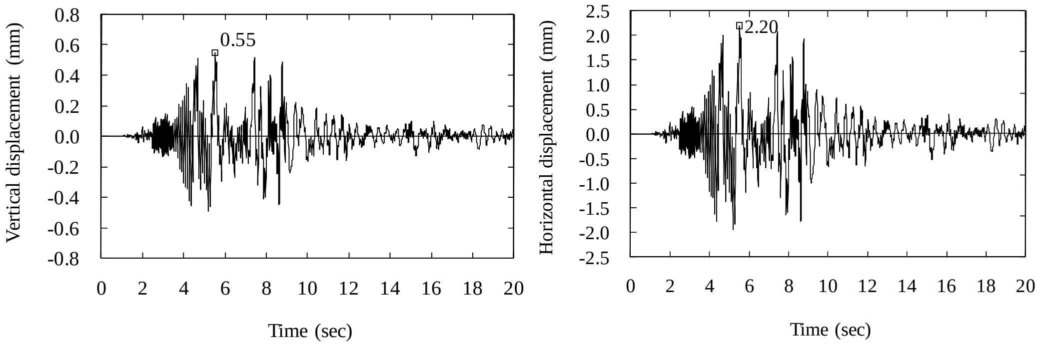


Figure 9: Time histories of the vertical and the horizontal displacement (T_f and A_{max} are 150 kPa and 650 gal, respectively.)

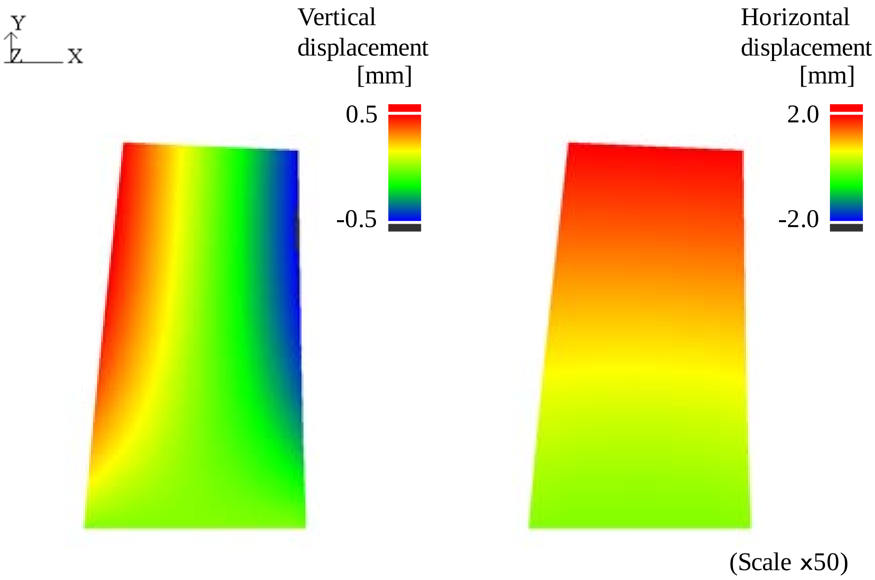


Figure 10: Distributions of the vertical displacement and the horizontal displacement (Time is 5.5 sec. T_f and A_{max} are 150 kPa and 650 gal)

5. CONCLUSION

In this study, mechanical properties and seismic behavior of a rammed earth wall made of a lime-mixed soil were evaluated. Finite element analyses of the seismic behavior of the wall were carried out employing an elasto-plastic model that can describe the mechanical properties of the lime-mixed soil which were obtained by some laboratory tests.

- The tensile strength of lime-mixed soil are very low and represent only 5% of compressive strength ones.
- In the case where the tensile strength of lime-mixed soil is 150 kPa, partial failure occurred at the bottom of the wall when A_{max} is between 525 gal and 650 gal, and it is followed by overall failure that took place when A_{max} is larger than 650 gal.
- Not shear failure but tensile failure would occur in the soil wall in the event of an earthquake.

- The wall response is more like a rigid body. The deformations of the wall exhibit rocking motion.
- In order to decrease the risk of overbalancing of the soil wall, the tensile strength should be evaluated correctly, and the tensile failure should be prevented.

REFERENCES

Hall M. R. (2007): Assessing the environmental performance of established reamed earth walls using a climatic simulation chambar, *Building and environment*, 42, 139-145.

Koseki J., Tsutsumi Y., Namikawa T., Mihira S., Salas-Monge R., Sano Y. and Nakajima S. (2008): Shear and tensile properties of cement-treated sands and their application to liquefaction mitigation, *Keynote Lecture, Proc. of 4th International Symposium on Deformation Characteristics of Geomaterials (IS-Atlanta 2008)*, 1, 27-50.

Namikawa T. and Koseki J. (2006): Experimental determination of softening relations for cement-treated sand, *Soils and Foundations*, 46(4), 491-504.

Namikawa T. and Koseki J. (2007): Evaluation of tensile strength of cement-treated sand based on several types of laboratory tests, *Soils and Foundations*, 47(4), 657-674.

Namikawa T. and Mihira S. (2007): Elasto-plastic model for cement-treated sand, *International Journal for Numerical and Analytical Methods in Geomechanics*, 31, 71-107.

Morel J. C., Mesbaha A., Oggerob M., Walkerc P. (2001): Building houses with local materials: means to drastically reduce the environmental impact of construction, *Building and Environment* 36, 1119-1126.

Interaction between degradation and self-healing behavior in high strength mortar exposed to high temperatures (up to 500 ℃)

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ABSTRACT

Recently, many researchers have been reported on the repair of fire-damaged concrete structures. These researches generally suggest that the repair process involve the removal and replacement of weakened layers of concrete with fresh concrete. However, no detailed examination of the interaction between the degrees of deterioration on various deterioration zones by heating and its re-hydration behaviors has been reported. Moreover, a few past studies indicated that the deteriorated concrete could regain its strength, without repairing, if properly recurred in water or a moist environment. In this paper, a comparative study of the degradation behavior of various zones, such as the dry and dehydrated zone, the drying and dehydrating zone, and the initial-state zone of cement paste close to surface area, of high-strength mortar is presented in order to clarify the self-healing behavior of high-strength mortar after damage by heating.

Keywords: *Self-healing, Degradation, Pore pressure, fire-damaged concrete*

1. INTRODUCTION

Concrete generally demonstrates good resistance to high temperature exposure compared with other building materials, and has been widely used for high temperature applications. However, it does undergo a loss of performance, such as decreased strength and spalling, depending on exposure time and temperature. Explosive spalling in particular has been observed inconsistently in laboratory tests due to the large number of variables which potentially affect its mechanism [1), as well as a lack of general guidelines for fire testing to provide a unified approach for measuring the effects of these variables. Kalifa et al. [2) proposed a degradation mechanism involving both thermo-mechanical processes related to thermal dilation gradients in the mortar and thermo-hydral processes due to mass transfer (air, vapor, and liquid water) in the pore network. The build-up of pressure in concrete under heating exposure is illustrated in Fig. 1. As heat flux drives water vaporization, the surface becomes a dry/dehydrated zone – a brittle layer composed of sintered material which cannot undergo re-curing. In the dry/dehydrating zone, evaporation of free and chemically-bound water is occurring but the material has not yet sintered, and the quasi-saturated zone contains water under heating. Degradation of high-strength concrete has been found to be more severe than normal-strength concrete due to increased loss of strength and higher occurrence of explosive spalling, which may be attributed to the low permeability of low water-cement ratio concretes and leads to increased pore pressure and thermal stresses. Build-up of pore-pressure is driven by "moisture clog spalling," in which water vapor migration under heating generates pore pressure which, when combined with thermal processes, results in spalling when the tensile strength of the matrix is exceeded.

Dry/dehydrating zone

Heating

Dry/dehydrated zone

Quasi-saturated zone

Pressure

Temperature

Distance from heated face

Fig. 1: Dehydration zones under heating (adapted from Kalifa et al.[2)])

Repair of fire-damaged concrete is necessary to restore degraded performance and commonly involves the removal of damaged areas and their replacement with fresh concrete or a patching material. However, past research has found that re-curing fire-damaged concrete in water can restore strength and durability through the re-growth of hydration products, development and filling of pore structure, and healing of cracks. High-strength concrete was also found to have better recovery under re-curing due to its dense microstructure [3)]; however, as discussed earlier, the degradation of high-strength concrete is more severe due to thermo-hydral and thermo-mechanical mechanisms, which may significantly reduce the repair effect due to re-curing. Therefore, the interaction between degradation and self-healing behavior under re-curing conditions should be clarified to further understand the potential for re-curing as a repair method.

In this paper, a study on the degradation behavior is presented in order to clarify the self-healing behavior of fire-damaged high-strength mortar during re-curing. Mortar was selected for this investigation to focus on the microstructure behavior and self-healing in the cement mortar matrix. The first part investigates the degradation behavior by examining the surface microstructure of zones with different dehydration levels and considers the deterioration mechanism in terms of solid-state-sintering of entrained pores. The behavior of entrained air formed by the usage of admixtures and the local stress incompabilities between the cement paste and aggregates are also investigated by microscopy. The second part deals with self-healing behavior of fire-damaged high-strength mortar under water supply considering the differing dehydration zones. The self-healing behavior is then connected to recovery of strength and porosity as observed in an additional study.

2. EXPERIMENTAL PROGRAM

2.1. Mortar specimens

High-strength cement mortar was prepared using ordinary Portland cement (Japan Type I) at a water-binder ratio of 0.35 and Fujigawa river sand, with a maximum particle size of 4.75 millimeters, at a sand-cement ratio of 1.8. Air-entraining and super plasticizer admixtures were also utilized to satisfy workability requirements. Beam specimens (40mm×40mm×100mm) were demolded 24 hours after casting and placed under water for 14 days at 20°C, then air-cured at 20°C and 60% relative humidity (RH) until high-temperature exposure at 28 days. Compressive strength at 28 days was 66.9 MPa.

2.2. Fire exposure and post-fire re-curing conditions

Specimens were exposed to high temperatures using an electric furnace. As this furnace does not have a control mechanism for the rate of heat increase, the furnace was preheated to the target temperature before beginning exposure. The temperature was set at 500°C for one hour in order to clarify the shrinkage of cement paste and local stress behavior by mass loss of $Ca(OH)_2$ as well as free water, and was selected based on past research which found that damage at temperatures beyond 500°C cannot be fully recovered. Specimens were allowed to cool at room temperature and conditions for one hour after exposure, and then re-cured in water-submerged conditions.

2.3. Estimation methods of transport properties

Fig. 2 shows the size of pores in concrete and their methods of measurement. This investigation is focused on super plasticizer-entrained air, which falls between 10 nanometers to several millimeters, so microscopy was selected for observation. SEM (scanning electron microscope) with EDS detector were utilized to investigate the morphology and shape of fire-damaged specimens and the size of the rehydration products in order to clarify the degradation mechanism and self-healing behavior. Three-dimensional (3D) digital microscopy images were also acquired using 3D visualization software in order to identify connected pores in entrained air. Thermo-gravimetric differential thermal analysis (TG-DTA) was used to analyze the mass transport of cement paste according to degradation area, and mercury intrusion porosimetry (MIP) was conducted to clarify the self-healing behavior. All specimens were analyzed during the healing process of cracked mortar specimens, and observations were performed at each location by following the paste-aggregate bond zones and cracks.

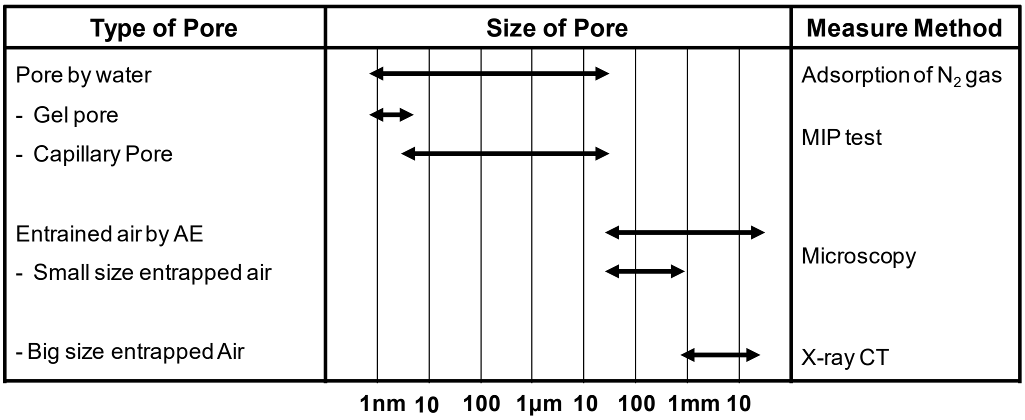

Fig. 2**:** Concrete pore types, sizes and associated measurement methods

3. RESULTS AND DISCUSSION

3.1. Degradation behavior of cement paste on surface area

Fig. 3 shows the surface morphology of deteriorated high strength mortar after 500°C exposure. Degradation occurred at the surface due to shrinkage of the cement paste, similar to the solid-state-sintering effect, and the specimen surface could be divided into dry/dehydrated or dry/dehydrating zones. The deteriorated surface of the dry/dehydrated zone after heating is shown in detail in Fig. 4. This zone was almost entirely sintered, and various phenomena were observed, such as solid-state-sintering, pore shrinkage, and volcano effect driven by increasing pore pressure. Mass loss in this zone may be attributed to the reduction of $Ca(OH)_2$ and evaporation of free water in the system within the one-hour heating period.

Pore shrinkage by dehydration of combined water such as solid-state-sintering was also observed (Fig. 5). In general, the solid-state-sintering on the surface due to heating affects the grain size and shape and pore size and shape, and is driven by a reduction in surface energy. Densification occurs as excess free energy builds up on the surface of cement paste, and the release of built-up surface energy leads to the formation of coarse grains which increase in size under heating.

Fig. 6 shows the sintered and combustion traces by EDS analysis in the dry/dehydrated zone. Many coarse grains can be seen at the surface, and their chemical composition is similar to $3CaO \bullet SiO_2$ due to dehydration of the cement paste at the surface.

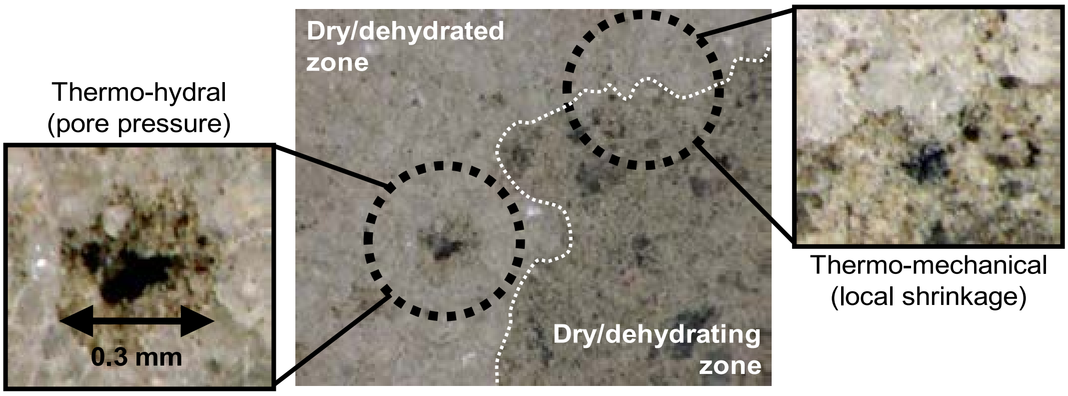

Fig. 3: Surface morphology of deteriorated mortar

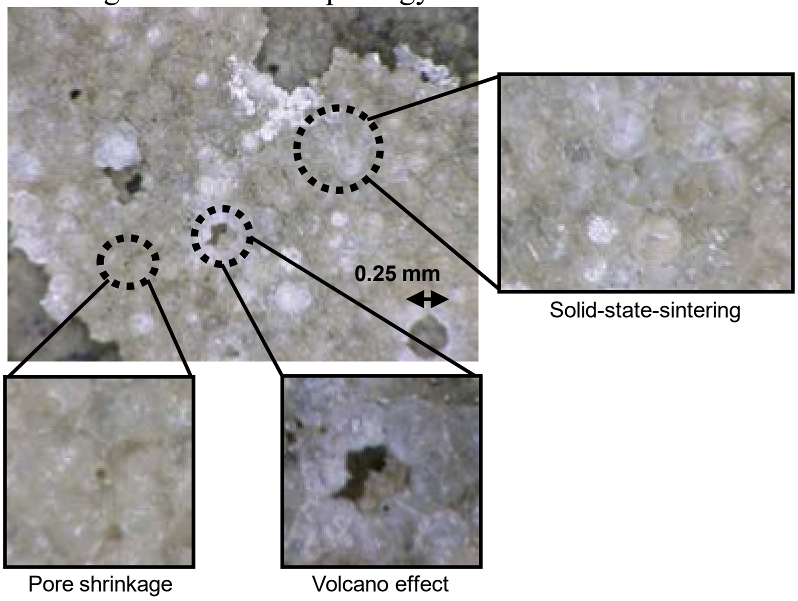

Fig. 4: Deteriorated surface of dry/dehydrated zone in detail

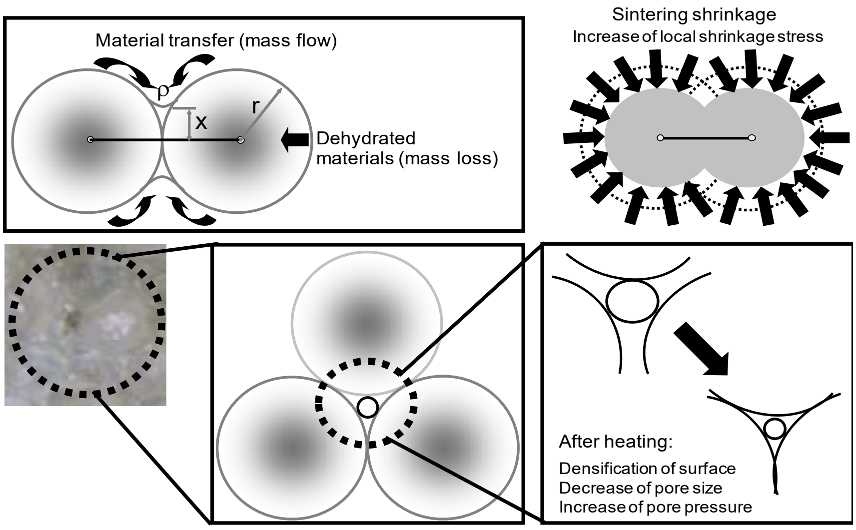

Fig. 5: Pore shrinkage by solid sintering in dry/dehydrated zone

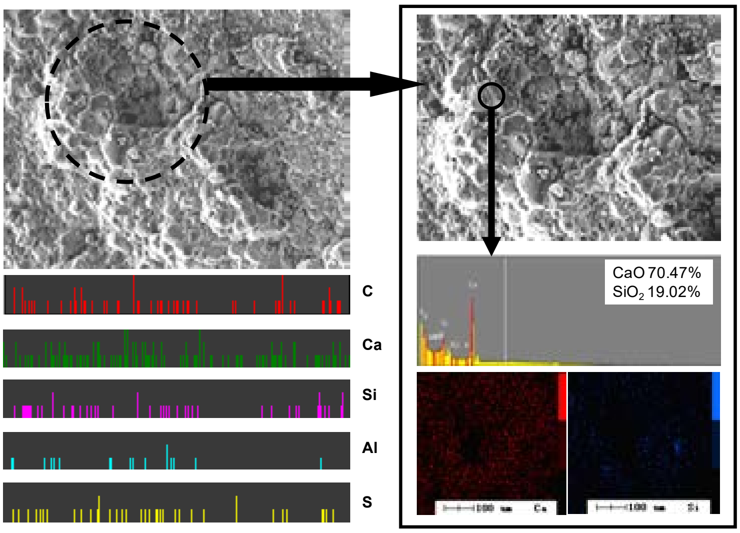

Fig. 6: X-ray spectrum of sintered mortar surface after heating

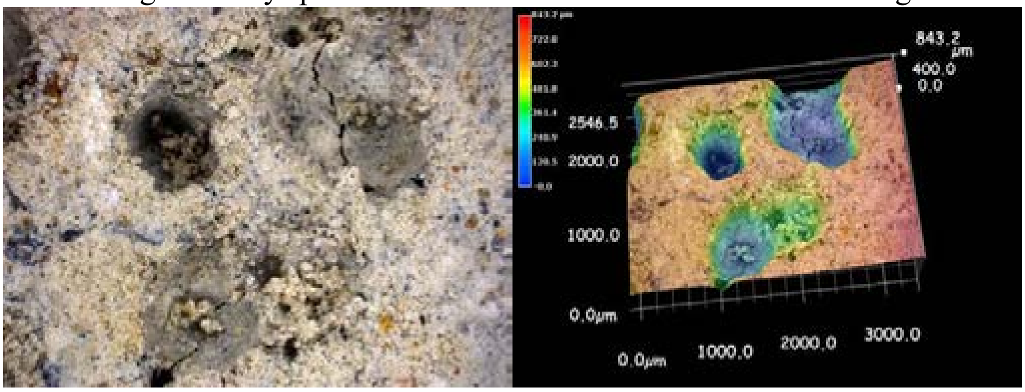

Fig. 7: Surface image and 3D visualization of surface degradation

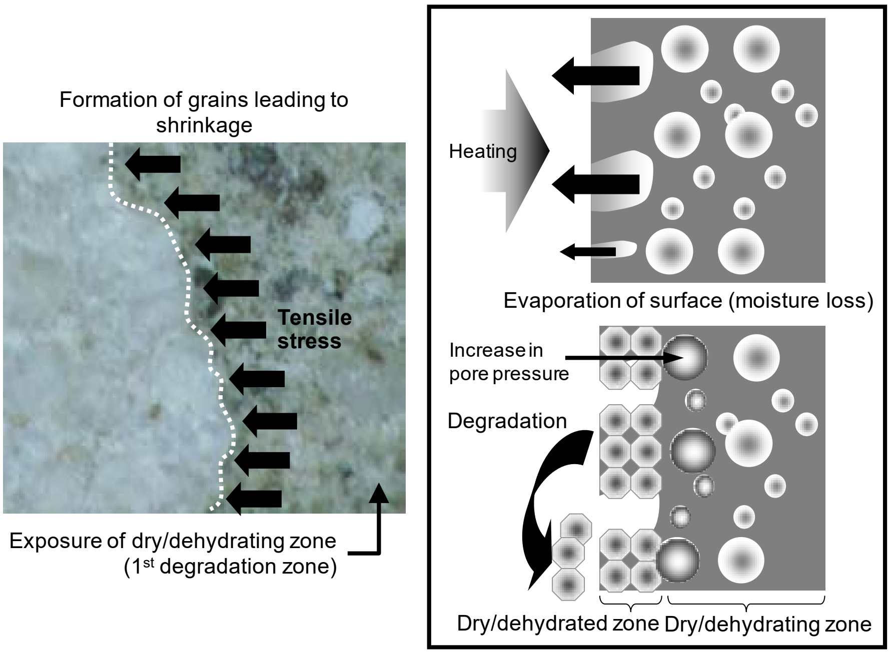

Fig. 8: Surface degradation phenomenon leading to exposure of dehydrating zone

The dry/dehydrating zone was partially exposed after degradation of cement paste in the dry/dehydrated zone as observed visually in Fig. 7, and the mechanism is illustrated in Fig. 8. The depth of the dry/dehydrated zone was measured at 0.08 to 0.1 millimeters, but this depth is dependent on heating time and temperature. Densification of the surface layer led to a thermo-hydral degradation process (volcano effect) caused by incremental increase of pressure within entrained air. This phenomenon will be discussed in detail in the following section.

3.2. Volcano effect of entrained air by pore pressure

Observation of the mortar surface layer found deterioration of the cement paste to a depth of 0.1 millimeters. Densification of the surface through solid-state-sintering based on dehydration led to a reduction in vapor flow, causing an incremental increase of internal pore pressure within entrained air and contributing to demolition of the dry/dehydrated zone – similar to the eruption of a volcano. This volcano effect may be affected by pore size, shape, and degree of moisture content within the pore; most entrained air between 0.3 and 1.0 millimeters under this heating exposure showed volcano effects.

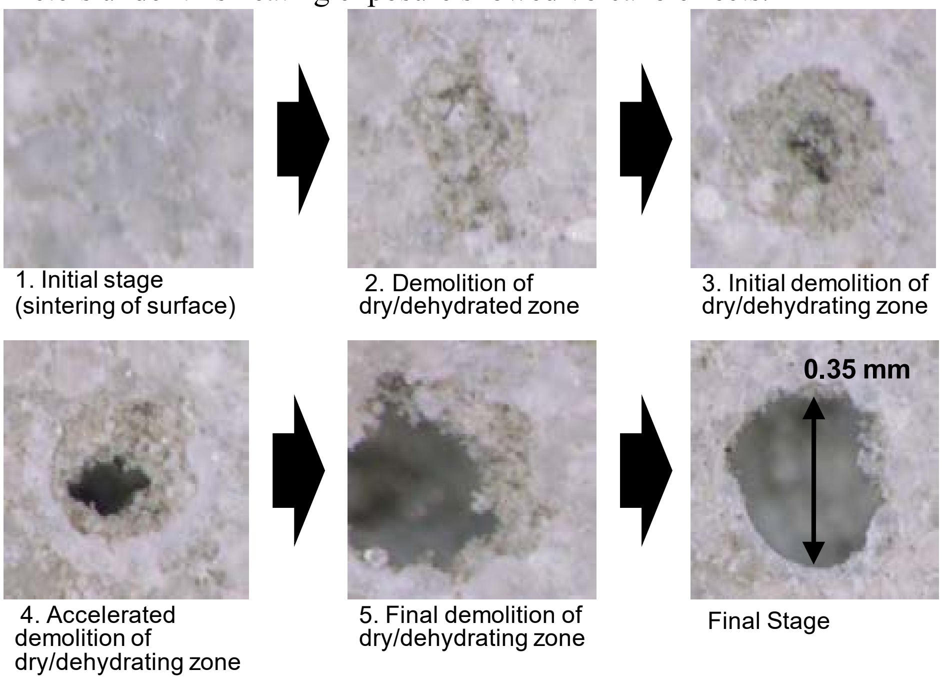

Fig. 9: Demolition process at the mortar surface by pore pressure

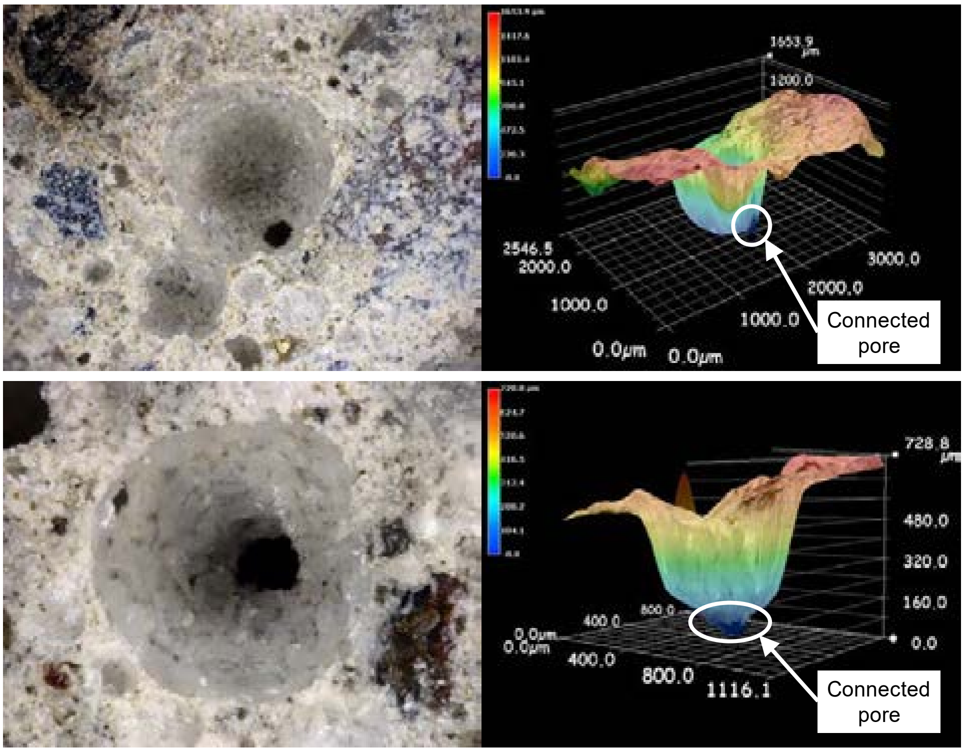

Fig.10: Surface images and 3D visualizations of volcano effect in connected pores

The demolition process of the dry/dehydrated and dry/dehydrating zones is illustrated in Fig. 9 through microscopy images, which show the degradation from surface sintering and demolition of the dry/dehydrated zone to demolition and of the dry/dehydrating zone. The volcano effect may also occur in conjunction with adjacent entrained air, where built-up pore pressure in the smaller pore exceeds the matrix strength and a connecting passageway is formed between the two pores. Pressure first drops due to larger space then increases again under heating until the volcano effect occurs at the surface, exposing both the entrained air pore as well as the adjacent, connected pore. The exposed connected pore can be clearly seen in both the surface images and 3D visualizations in Fig. 10 for two different locations where the volcano effect was observed. This section and the preceding section discussed the degradation of mortar under heating exposure and examined the mechanism considering the progress of the dry/dehydrated and dry/dehydrating zones and the build-up of pore pressure in entrained air. The following section will move towards the next step, the repair of fire-damaged mortar, by examining the self-healing behavior under water supply.

3.3. Self-healing behavior of high-strength mortar

Sintered materials lose their self-healing capability due to the sintering effect; this is clearly seen in Fig. 11, in which 28 days re-curing in water shows no effect on the sintered material. On the other hand, the dry/dehydrating zone is not yet sintered but in the dehydrated condition, indicating there is potential for re-curing if water is supplied to this zone. Fig. 12 shows that the self-healing effect occurs in the dry/dehydrating zone even after one day of re-curing, and by 28 days the crack was almost entirely self-healed.

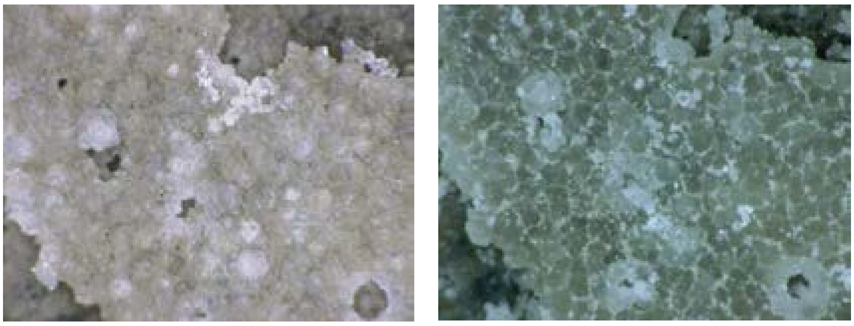

Fig. 11: Loss of self-healing capability by sintering in the dry/dehydrated zone

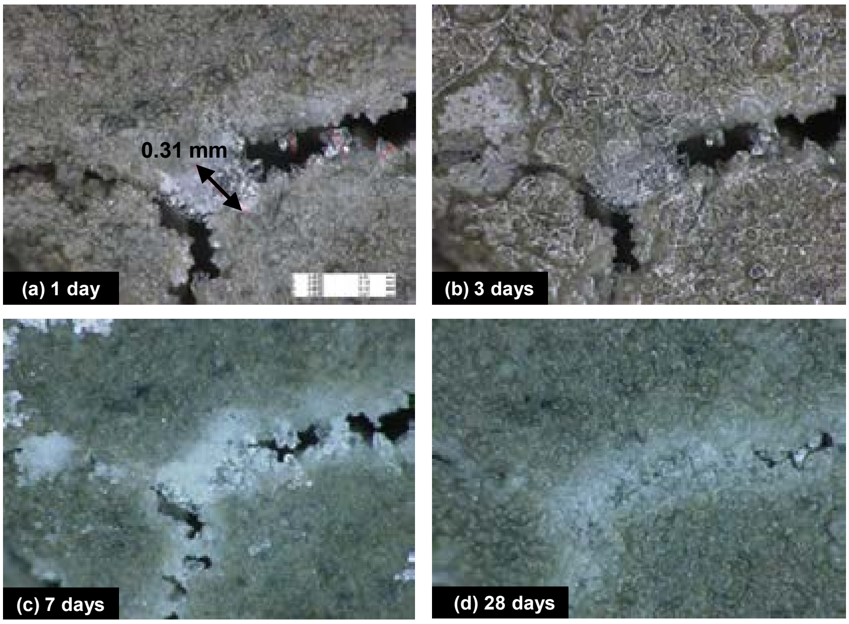

Fig. 12: Observed self-healing behavior in dry/dehydrating zone (I)

The self-healing phenomenon also occurred in the entrained air structures for the dry/dehydrated, dry/dehydrating, and quasi-saturated zones. In the dry/dehydrated zone, it was found that self-healing behavior did not occur due to the pore sintering effect. For the dry/dehydrating zone, there was partial self-healing although sintering was also observed. In the quasi-saturated zone, almost complete self-healing occurred after 28 days. This demonstrates that there is high potential for fire-damaged mortar and, by extension, concrete to recover mechanical properties if re-cured under appropriate water supply conditions.

3.4 Strength and porosity recovery

A complementary investigation on self-healing under water curing was conducted by the authors but with a water-cement ratio of 0.3 and exposure temperature of 550°C. The compressive strength and porosity were examined before heating, after 1 hour of water cooling, and after 28 days re-curing, with the relationship between strength and porosity shown in Fig. 13.

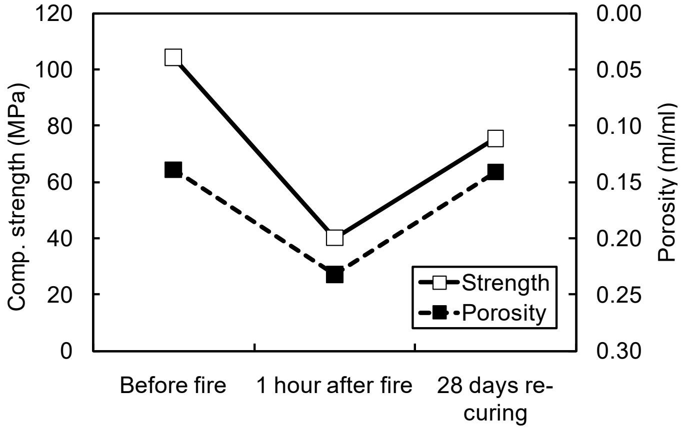

Fig. 13: Change in strength and porosity after heating and water re-curing

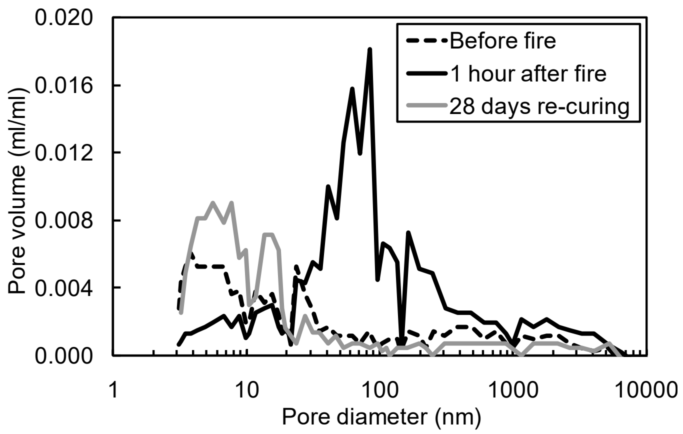

Fig. 14: Change in pore distribution after heating and water re-curing

Recovery of both properties can be clearly observed, but strength only recovers to 72% of its original value whereas porosity is observed to completely recover after 28 days water re-curing. This discrepancy between the strength and porosity behavior may be explained by self-healing behavior observed for similar specimens in the previous section; specifically, although full crack self-healing was observed to occur after 28 days of re-curing in water (Fig. 12), the stability of this new, self-healed interface is unknown and may contribute to the lack of full strength recovery. In addition, while the porosity completely recovers by 28 days, the pore distribution is slightly different, as can be seen in Fig. 14. Pores less than 11 nanometers in size occupy a greater volume than they did before heating, with pores greater than 11 nanometers in size occupying less volume after re-curing than before heating, suggesting that re-curing in water after heating may lead to an increase in gel pores and a decrease in capillary pores relative to the pre-fired conditions.

4. CONCLUSION

In this paper, the degradation and self-healing behavior of fire damaged high-strength mortar was investigated in order to support concrete recycling and to develop a new repair method for fire-damaged concrete. Key findings are as follows:

- Degradation behavior of the cement paste on the mortar surface could be related to thermo-hydral and thermo-mechanical processes under heating. Solid-state-sintering due to dehydration, pore shrinkage, and volcano effect were observed by microscopy. The volcano effect was proposed to explain degradation at the mortar surface. This phenomenon is driven by the build-up of vapor pressure in entrained air which leads to demolition of the dry/dehydrated zone. It was observed that this occurred both in single pores and connected pores near the mortar surface.
- Self-healing behavior was observed in both cracks and in entrained air in the dry/dehydrating and quasi-saturated zones, which demonstrated the potential for self-healing behavior in fire-damaged high-strength mortar. No self-healing behavior was found to occur in the sintered dehydrated zone, which may limit recovery capability depending on the extent of exposure.

Secondary degradation may occur due to the weak bond between the dry/dehydrated and dry/dehydrating zones. In order to reduce this effect, the development of a chemical bonding agent for a water-based re-curing process could lead to the practical development of a new repairing method.

ACKNOWLEDGEMENTS

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REFERENCES

1) V. Kodur, Fiber reinforcement for minimizing spalling in high strength concrete structural members exposed to fire, in: ACI SP-216, Innovations in Fiber-Reinforced Concrete for Value, ACI, Farmington Hills, 2003, pp. 221-236.
2) P. Kalifa, F.D. Menneteau, D. Quenard, Spalling and pore pressure in HPC at high temperatures, Cement and Concrete Research 30 (2000) 1915-1927.
3) T.H. Ahn, Development of self-healing concrete incorporating geo-materials: a study on its mechanism and behavior in cracked concrete, Ph.D. dissertation, Dept. of Civil Engineering, The University of Tokyo, Tokyo, 2008.

Impact of Climate Change on Waste Water Reticulation System: A Case study in Drouin, Australia.

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ABSTRACT

Australia being an island continent is highly vulnerable to infrastructure damage due climate change. The sewer reticulation systems are not an exception. Research needs to be carried out to quantify the impacts of climate change and design criteria be reviewed, to mitigate or adapt to the impacts of climate change in the waste water reticulation system. Although much of Australia is expected to dry because of climate change, due to decrease in total rainfall, increase in extreme rainfall events are still expected in many regions. This will affect the sewer reticulation system in many ways.

The aim of the research is to quantify the impacts of climate change on a sewer reticulation system in urban areas of the Gippsland region, Victoria. The specific objectives are to simulate the impacts of climate change in a working calibrated sewer model and to analyse, understand and quantify the impacts in an existing waste water reticulation system based on the modelling. The model is used to simulate various scenarios individually and collectively to assess the impacts of climate change and quantify them. The simulated outputs give us a chance to quantify the impacts of the possible effects of climate change on the catchments and their characteristics. Drouin, a regional township in the Gippsland region, has been selected as the case study area for quantification of climate change on the wastewater reticulation system.

The paper presents the detailed outcomes of the case study. The results demonstrate that there will be significant effects of climate change at several locations of the selected systems including reduction of inflow to the system. The reduction in inflow would result in the reduction of the velocity of flow, which in turn would reduce the self cleansing velocities. These results would help the water authority to prepare adaptation measures and in designing the sewer reticulation systems in future to cater for the impacts of climate change.

Key Words: Waste Water Reticulation Systems, climate change, impacts and adaptation.

1. INTRODUCTION

Climate change manifests itself through an elevation in average temperature, variation in rainfall patterns or an increase in sea level and thereby poses a significant risk to infrastructure and its owners, managers and long-term operators.

According to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the 100-year linear trend (1906-2005) of average global temperature rise of 0.74°C [0.56 to 0.92]°C is larger than the corresponding trend of 0.6°C [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR) (IPCC, 2001 and 2007).

Australia being an island continent is highly vulnerable to infrastructure damage due climate change. Australia's average temperatures have already risen by around 0.7°C over the last century. Victoria has warmed by 0.6°C since the 1950s and the last ten years have been hotter than average, with 2007 being the hottest year on record. By 2030 warming in Victoria is likely to range from 0.6°C to 1.2°C on 1990 temperatures and by 2070 from 0.9°C to 3.8°C. There will be more hot days and fewer cold days. Widespread decreases in atmospheric moisture are likely over Victoria. Increases in extreme daily rainfall are likely, but decreases are also possible in some regions and seasons. An increase in fire-weather risk is likely. Relative to 1990, sea level may rise by 3 to 17 cm by 2030 and 7 to 52 cm by 2070 (Howe *et al.*, 2005, Atkinson *et al.*, 2007, Holper *et al.*, 2007). These changes will have impacts on the urban infrastructure including the waste water systems.

The Victorian Government's '*Victorian Greenhouse Strategy Action Plan Update'* (Victorian Government, 2005) acknowledged the need of appropriate decisions to ensure that the outcomes of those decisions were robust enough to cope with, or adapt to, changing climatic conditions in the future for various key areas including urban infrastructure. A research, commissioned by Victorian Government to study the risk exposure to key aspects of climate change of some key areas of Victoria including infrastructure, found that the water and wastewater infrastructure sector is exposed to the highest risk due to climate change (Holper *et al.*, 2007). The main risks associated with climate change are the potential for increased frequency of extreme daily rainfall events, affecting the capacity and maintenance of storm water, drainage and sewer infrastructure. There are likely to be significant damage costs and environmental spills if water systems are unable to cope with extreme events or multiple events in a season. Acceleration of the degradation of materials and structural integrity of water supply, sewer and stormwater pipelines may occur through increased ground movement and changes in groundwater. Water shortages may occur due to greater demand for water associated with increased temperatures, reduced available moisture and increased population. A decrease in annual rainfall in catchments would affect water supply.

In several parts of Victoria, especially in rural towns, it has been already witnessed that flows into the sewer treatment plants have been affected due to the water restrictions, more efficient water-using appliances and recycling of water in homes and on farms in the past few years Managing director of agricultural research consultancy Arris Pty Ltd, Dr Daryl Stevens, reportedly stated that "flows into most Australian sewage treatment plants are declining dramatically, especially in drought-affected country towns". He says water restrictions, more efficient water-using appliances and recycling of water in homes and on farms are all contributing, and Australia's sewage system may struggle to cope with waste

(Grant, 2009). The amount and volumes of water have decreased 10% to 30% going in to some sewage treatment plants. The whole sewage system is designed on a certain volume of water flushing through it to carry all the solids that are mixed up in the water. This has resulted in less waste water in the pipes as drains and sewers dry up. This is an example of how climate change alters the behavioural patterns and water usage of people.

There is a critical need for research to develop comprehensive understanding and for quantification of the impacts of climate change on water and wastewater infrastructure for appropriate adaptation measure and retrofitting of existing infrastructure and designing new infrastructure to withstand the climates of today and the future. The solutions may vary from , "Do nothing", or increase the slope of the pipes, or change the material of the pipe, increase or decrease the diameter of the pipes, Increase the capacity of the wet well and or emergency storage, special odour control systems etc.

This study was undertaken as an attempt to quantify the impacts of climate change on a sewer reticulation system in urban areas of the Gippsland region, Victoria. The paper presents the outcomes of the project with a case study application in Drouin Township in the Gippsland Region of Victoria.

2. CASE STUDY AREA

Central Gippsland Region Water Corporation trading as "Gippsland Water" (GW) provides water and sewer reticulation systems services for the town Drouin. Figure 1 shows the catchment areas and the townships served by GW including Drouin. The township of Drouin is located about 90 kilometers east of Melbourne cantered along the Princes Highway.

The Drouin sewerage catchment contains approximately 61 kilometers of sewer, and covers a gross area of 246 hectares serving a population of approximately 5,815 persons. The catchment is entirely situated in the local government area of Baw Baw Shire and is predominantly residential, with some commercial, industrial and public use areas. Approximately 76% of the pipes within the Drouin Catchment are 150mm in diameter or less, 14% are 225-300mm in diameter, 6% are 375-525mm in diameter, while the remaining 4% are pressure pipes. A majority of the existing catchment is situated in close proximity to Princes Hwy. Approximately 80% of Drouin is residential. The main commercial and industrial areas are within or in close proximity to the town centre. The sewerage catchment drains towards the trunk sewers running parallel to Princes Hwy where the flows travel westward to the Drouin Wastewater treatment plant (WWTP). After treatment the treated effluent is discharged to Shillinglaw Creek under the GW amalgamated EPA (Environmental Protection Agency) discharge license.

There are no emergency relief structures within Drouin. There are six sewerage pumping stations operated by GW contained within the Drouin Sewerage Catchment Area Plan SCAP, of which Hopetoun Road Sewer Pump Station (SPS) is the only major pump station. The Drouin SCAP is serviced by approximately 61km of sewers and 1,170 manholes.

Figure 1: Gippsland Water general Operations (Wilbraham, 2007)

The existing reticulation systems have been designed initially using the guidelines of Water Services Association of Australia (WSAA) and Gippsland water's Wastewater Systems Design Performance Criteria. This has been developed based on the experience and the observed results over the years. GW's Engineers over the years have formulated these guidelines and are still improvising them as required.

In a Greenfield situation, GW follows the Water Services Association of Australia (WSAA) guidelines to design its reticulation system. WSAA estimates the design flow using the formula (WSAA, 1999):

Design Flow = PDWF+ GWI+ IIF

Where,

PDWF = Peak Wet Weather Flow
GWI = Ground Water Infiltration
IIF = Inflow Infiltration

However like most of the water authorities, GW has its own "Wastewater Systems Design Performance Criteria" as mentioned above. The assumptions are to be tested in conjunction with the impacts of climate change and there is a need for further research in this area.

The basic assumptions Gippsland Water's Wastewater Systems Design Performance Criteria are:

- Average Dry Weather Unit flow = 650L/Lot/d
- Ip (Permanent Infiltration) = 500L/ha/d
- Is (Storm dependant infiltration)= 25,000L/ha/d

These assumptions are revisited as the climatic conditions and the usage patterns have considerably changed in the recent years. Further to achieve this, a calibrated model (Info works) has been used to simulate the impacts of climate change on the existing systems and sub catchments to verify the assumptions.

GW engaged Montgomery Watson Harza (MWH) to install flow meters and rain gauges at various locations in the above mentioned catchment and to record the readings in five minute intervals for four months continuously. These readings were used to calibrate the model (Info works) used by GW. The flow meter readings were used to analyse the various parameters like Average Dry Weather Flow (ADWF), Peak Wet Weather Flow (PWWF), Storm water Infiltration (Is) and Dry weather Infiltration (Ip).

Five flow monitors were installed by ADS for the temporary monitoring of the Drouin Sewer Catchment. The flow meter locations can be seen in Figure 2. Manhole M/A defines the outlet of the Drouin SCAP which discharges to the Drouin WWTP. The Drouin SCAP boundary is defined by flow monitor DR1. The remaining temporary monitors define each of the sub-catchments within the Drouin Catchment.

From the flow meter readings for four months for Drouin catchment were analysed and it was found that the values were different for different sub-catchments. For example at Drouin, Table 1 shows the Average dry weather unit flow per lot per day which is less than the assumed flow of 650L/Lot/day in the GW's Wastewater Systems Design Performance Criteria. This clearly shows that the conservation and reuse of water by the people is eminent.

Table 1: Average Dry weather unit flows for Drouin catchment

Station	Residential Generation Rate	Non Residential Rate
Flow Meter Location	ASF/Lot/Day	L/connection/day
DR1	630	630
DR2	390	390
DR3	620	620
DR4	420	420
DR5	520	520

There is a wide range of differences between the above catchments. The catchment DR 5 is almost fully developed and is mostly residential. The catchment DR 1 still has provision for 55 residential connections and has 80 non-residential connections connected. DR3 has the potential for an additional 32 connections as Drouin Town ship is not fully developed.

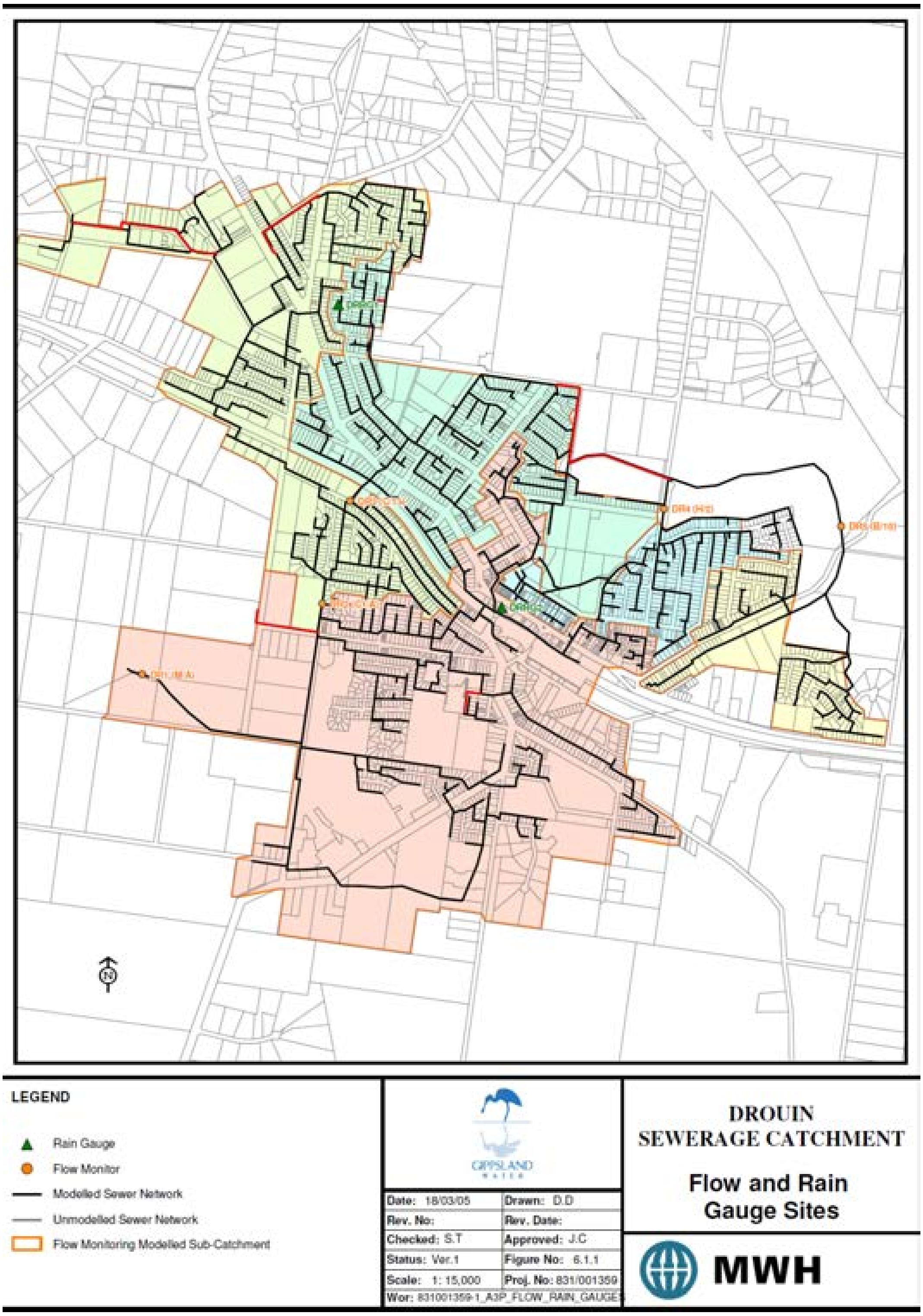

Figure2: Drouin Sewerage Catchment Plan (adopted from Theodorlis, 2006)

3. INFO WORKS MODELING SOFTWARE

Info works Wallingford sewer modelling Software CS has been used for this study. This model was developed in UK and is now used worldwide as one of the most reliable models. The model has the features to simulate and run different scenarios and the predicted impacts of climate change are being applied to the calibrated model and the results are analysed. The model has been calibrated by MWH for Gippsland Water and GW has given the 1st author permission to use this calibrated model for the research. Quantity analysis of the data was done by MWH and it was found that 99% of the data recorded were good. For each catchment waste water generations were created separately for residential and non residential profiles. Specialist profiles have been created for Schools, Hospitals, Parks

The current hydraulic model was calibrated in Info Works CS 5.0 for dry and wet weather conditions using data obtained from five (5) flow monitors, and two (2) rain gauges collected over a nine week period. Info works CS Fixed Runoff model coupled with groundwater infiltration module was utilised to calibrate the model to wet weather conditions due to the extensive wet weather response recorded in the system. Dry and Wet weather system performance for existing (design) loading conditions was assessed using the calibrated hydraulic model.

The sub-catchment boundary is defined by the extent of the contributing areas which exist between an Upstream and downstream flow monitor. The difference in flow between monitors represents the flow attributed to each sub-catchment. The GW's model requirements specify the following tolerances as given in Table.2.

Table 2: GW's requirements for dry and wet weather modeling

Wet weather model requirements	**Dry weather model requirements**
±10% for peak discharge;	±5% for peak discharge;
·±10% for daily flow volume;	±5% for daily flow volume;
Peak timing ±30 minutes;	Peak timing ± 30 minutes;
±20% for depth of flow; and	±15% for depth of flow; and
Shape representative of observed flow pattern	Shape representative of observed flow pattern

Climate Change Scenarios for simulation

One of the major impacts of climate change to the sewer reticulation system is reduction of inflow in the waste water reticulation systems due to water restrictions, water saving devices and grey water reuse. GW is already experiencing this as the population is increasing but the inflow in to the waste water treatment plants are decreasing. Figures 3 and 4 shows the increase in population of different towns within the GW catchment and the reduction of water usage by the GW customers in the recent years. This is mainly due to the use of water saving water efficient devices, grey water reuse, use of rain water tanks, water restriction and the mindset of the people.

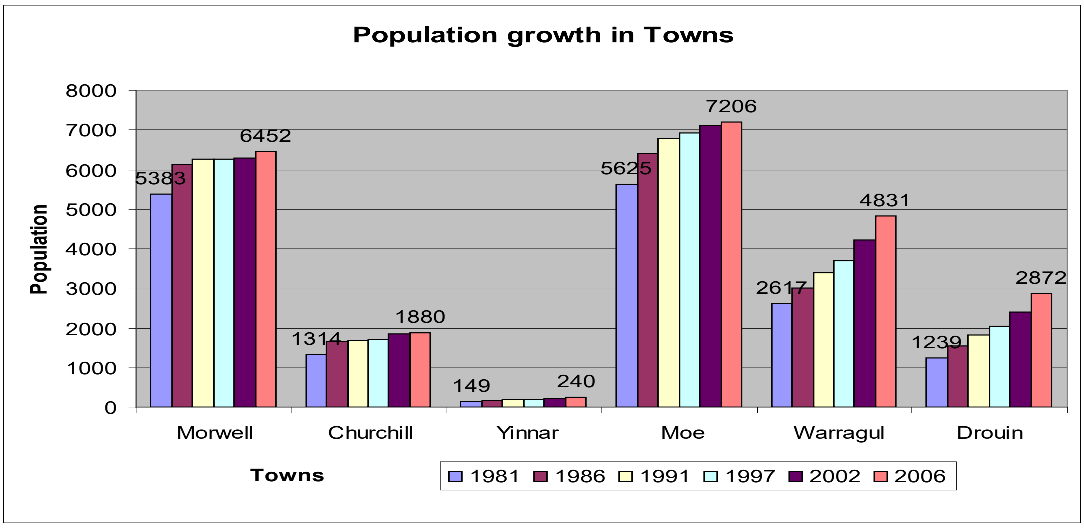

Figure 3: Increase in Population in various towns.

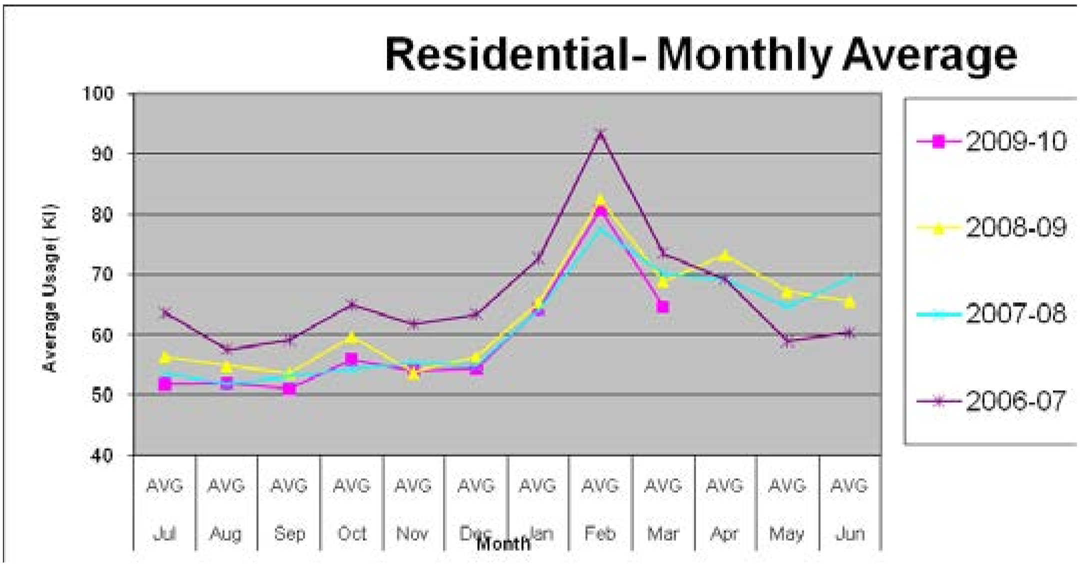

Figure 4: Decrease in Water consumptions leading to decrease in inflow to the WWTPs

It has been predicted that the reduction in the waste water inflow to the Waste water treatment plants would range from 10% to 30%. The calibrated Info works model for Drouin was simulated for the scenarios of reduction in inflow by 10%, 20% and 30 % and the changes in depth in the pipe, velocities in the pipe and the flow were analysed.

4. RESULTS AND DISCUSSION

Reduction in Velocity in pipe due to reduction in inflow

Table 4 presents the simulated maximum, minimum and average velocities of flow in the sewer network in DR1 due to the reduction in inflow by 10%, 20 % and 30 %. The results show that the reduction in minimum velocity is highly significant with about 20% reduction due to the reduction of inflow by 30%. This is going to have impacts on self cleansing velocity of the system. The flow velocity in the sewers should be such that the suspended materials in sewage do not get silted up; i.e., the velocity should be such as to cause automatic self-cleansing effect. The generation of such a minimum self cleansing velocity in the sewer, at least once a day, is important, because if certain deposition takes place and is not removed, it will obstruct free flow, causing further deposition and finally leading to the complete blocking of the sewer.

Table 4: Change in velocity due to change in inflow at DR1.

Sensitivity Analysis	**Normal DS Velocity (m/s)**	**Simulated DS Velocity (m/s) – 10% reduction in inflow**	**Difference in %**
Max	0.26	0.25	2.99
Average	0.18	0.17	6.29
Min	0.11	0.10	6.05
	Normal DS Velocity (m/s)	**Simulated DS Velocity (m/s) – 20 % reduction in Inflow**	**Difference in %**
Max	0.25	0.22	13.28
Average	0.18	0.15	12.73
Min	0.11	0.10	13.27
	Normal DS Velocity (m/s)	**Simulated DS Velocity (m/s) – 30 % reduction in Inflow**	**Difference in %**
Max	0.25	0.21	18.93
Average	0.18	0.14	19.31
Min	0.11	0.09	20.37

Reduction in flow depth in pipe due to reduction in inflow

The depth of flow in the sewer is a major factor responsible for the sewer transport. The sewer consists of solids and liquids and if the depth of flow in the sewer is very less, it leads to settlement of solids to the bottom of the pipes and due to the nature and the texture of the waste; it starts to build up and ultimately blocks the sewer. A sensitivity analysis has been carried out and the results have been tabulated in Table 5. It is found that that the depths of flow in the sewer system were reduced as the inflow reduced. .the maximum water depth in the pipe is reduced from 0.32 m to 0.3m due to 30% reduction in inflow .The depths play a vital role in the transport of sewer in the pipes. The reduction in depth will have its impact on the self cleansing velocities in the sewer system. Previous research on self cleansing velocities state that reduction in depth in the sewer flow to more than 0.5 of the pipe would result in considerable amount of deposition and reduction in the shear force required to cleanse the system. Self cleansing velocities also depend on the diameter of the sewer pipe (Nalluri *et al.*, 1994). It is clear that a reduction in 20% of the inflow to the reticulation system affects the hydraulics of the system considerably. In reality we have seen from reports that the inflow to the waste water treatment plants are already reducing by 25 to 50%.

Table 5: Change in depth due to reduction in inflow at DR01

Category	Depth in Pipe Normal DWF	Depth in Pipe 10 % reduction in inflow	Difference in %
Max	0.32	0.32	0.92
Average	0.29	0.28	1.50
Min	0.26	0.26	1.08
Category	**Depth in Pipe Normal DWF**	**Depth in Pipe 20 % reduction in inflow**	**Difference in %**
	Depth in Pipe Normal DWF	20 % reduction in inflow	
Max	0.32	0.31	4.10
Average	0.29	0.28	3.04
Min	0.26	0.26	2.33
Category	**Depth in Pipe Normal DWF**	**Depth in Pipe 30 % reduction in inflow**	**Difference in %**
	Depth in Pipe Normal DWF	30 % reduction in inflow	
Max	0.32	0.30	5.83
Average	0.29	0.28	4.63
Min	0.26	0.25	3.54

Reduction in flow in pipe due to reduction in inflow

The model was simulated to run for a period of three days during the dry weather flows. The results were confirming that the Downstream Flow, velocity and depth are decreasing proportionally as the inflow was reduced. Table 6 displays the sensitivity analysis with the maximum, minimum and average changes for the reduction of 10, 20 and 30 percent reduction of inflow to the down stream flow.

Table 6: Change in Downstream Flow due to Reduction in inflow at DR01

Sensitivity Analysis	Normal DS Flow (m3/s)	10 % less Inflow – Simulated DS Flow (m3/s)	Difference in %
Max	0.03	0.03	4.17
Average	0.02	0.02	8.19
Min	0.01	0.01	7.39
	Normal DS Flow (m3/s)	**10 % less Inflow – Simulated DS Flow (m3/s)**	**Difference in %**
Max	0.03	0.03	17.90
Average	0.02	0.02	16.40
Min	0.01	0.01	16.06
	Normal DS Flow (m3/s)	**10 % less Inflow – Simulated DS Flow (m3/s)**	**Difference in %**
Max	0.03	0.02	25.08
Average	0.02	0.02	24.56
Min	0.01	0.01	24.32

5. CONCLUSIONS

The paper presented the outcomes of a case study conducted to analyse the impacts of climate change in the waste water reticulation system in Drouin township of Gippsland Region using an established mathematical model. It is evident that the impacts of Climate change would affect the waste water reticulation system and the various parameters. The reduction in inflow would result in the reduction of the velocity of flow, which in turn would reduce the self cleansing velocities. The depth of the flow is also reduced due to the reduction in the inflow to the reticulation systems.

REFERENCES

Atkinson, N., P. Brait, L. Murphy and N.Rogers (2007), Victorian Local Government Greenhouse and Climate Change Case Studies Report, Municipal Association of Victoria 2007, 80 pages.

Grant R., 2009. *Increased water recycling leaves sewers struggling to flush* retrieved from http://www.abc.net.au/rural/news/13/02/2009 viewed on 01/12/2009.

Holper, P., S. Lucy, M. Nolan, C. Senese and K. Hennessy (2007) (ed). Infrastructure and climate change risk assessment for Victoria, Report to the Victorian Government, March 2007 Prepared by CSIRO Maunsell Australia Pty Ltd, Phillips Fox, 177 pages.

Howe C., Jones R.N., Maheepala S., Rhodes B., 2005. *Implications of Potential Climate Change for Melbourne's Water Resources* Melbourne Water Climate Change Study, Australia, 2005.

IPCC (2007). Climate Change 2007, 4th Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (AR4), United Nations.

IPCC (2001). Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK

Nalluri C., and Dabrowski W., 1994. *Need for New Standards to Prevent Deposition in Wastewater Sewers*. Journal of Environmental Engineering, Vol. 120, No. 5, pp. 1032-1043, September/October 1994.

Sewerage Code of Australia WSA 02-1999. Standards Australia, Melbourne.

Theodorolis S., 2006. Churchill- Boolarra- Yinnar Sewage Catchment Hydraulic Modeling. *Engineering Report. Vol **1**, August, 2006* Gippsland Water

Victorian Government (2005) Victorian Greenhouse Strategy Action Plan Update. Victorian Government Department of Sustainability and Environment, Melbourne, http://www.greenhouse.vic.gov.au/images/VicGreenhouse-ActionPlan.pdfWatson R., Zinyowera M.C., and Moss R.H., 2008. *Technologies Policies and measures for mitigating climate change.* Technical Report.

Wilbraham D., 2007. *Gippsland Water's Catchment Area.*Gippsland Water World Series Poster, Gippsland Water, Australia.

CLIMATE DISASTER RESILIENCE INDEX (CDRI) IN CHENNAI, INDIA

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ABSTRACT

Due to the rising pressures on Chennai, India, to provide the rapidly growing population (urbanisation) adequately with urban services (water, electricity, solid waste collection, etc.), the local government and communities are key actors in shaping the resilience of the city to climate-related disasters. Proposing a tool named Climate Disaster Resilience Index (CDRI), it shall understand the vulnerabilities and capacities (resilience) of physical, social, economic, institutional, and natural aspects of Chennai at the micro-level (zone-level). The key aim of this CDRI is to provide local governments with a planning tool in order to make the city resilient to climate-related disasters. This shall trigger the development of appropriate and feasible disaster risk reduction measures, or so-called sound practices.

CDRI results from the ten administrative zones of the city of Chennai highlight zone-wise the differences in terms of becoming resilient to climate-related disasters; however, do not confirm that urbanisation is necessarily negative for a city to become resilient, especially with regards to the physical dimension (provision of urban services and infrastructure quality). The outcome provides all the ten zones with individual results to the five aspects mentioned above. In addition to individual zone-based results, the CDRI allows cross-correlations between different parameters, for instance, high income levels of people is closely related to higher levels of material wealth (household assets).
The CDRI engages different stakeholders from local government, academia, to communities and may well represent the local conditions.

Keywords: ***urban disaster resilience, climate change, disaster risk reduction***

1. INTRODUCTION

This paper shall address the ongoing pressures resulting from trends of urbanisation and projected future climate change impacts in Chennai, India. Chennai being located at the south-eastern coast of India along the Bay of Bengal is not only experiencing rapid population growth rates since many decades (Chennai Master Plan, 2008), but may also become susceptible to predicted more frequent and severe climate change related hazards (IPCC, 2007) in the form of intense rainfall events leading to flooding, storms from cyclones formed over the Bay of Bengal mostly between October to December and potential heat waves and droughts during the dry period between April and June (Revi, 2008). While climate change impacts are not yet visible or statistically proven to become more intense or frequent, the population of Chennai has already risen significantly over the last decades by 1-3 percent per year, and demonstrates a serious risk driver. At current, the population growth rate lies around the global average (1.76 percent per year) for urban areas (UNDESA, 2010) at 1.72 percent per year; however, with large variations within different zones of the city (Chennai Master Plan, 2008).

The approach taken in this paper is to understand impacts of various risk drivers (e.g. urbanisation) on the provision of urban services, like water, electricity or solid waste disposal, just to name a few. Put it in other words, how the different sectors of a city are likely to sustain or bounce back in case an occurring climate-related hazard (shock) turns into a disaster. The perception of the city being more than just the social fabric or a physically defined entity (Godschalk, 2003: Vale and Campanella, 2005) is crucial in understanding the adopted Climate Disaster Resilience Index (CDRI) where physical and social aspects of a city are added by economic, institutional and natural issues related to climate-related disasters.

Ultimately, the CDRI aims to unveil the sectors which are more or less resilient to climate-related disasters; additionally, which areas among the ten zones of Chennai are likely to cope better during such disasters. This approach follows the main goal to make cities – in this case Chennai – safer to disasters ,which is also emphasised through the Hyogo Framework for Action (HFA) 2005-2015 (UNISDR, 2005, 2007, 2010), and gains now even more importance as Chennai is actively taking part in the 2010-2011 World Disaster Reduction Campaign: Making Cities Resilient. The aim of this campaign is similar to what the CDRI stands for which is raising the awareness among local governments/institutions to embark on a new way of thinking that action needs to be taken where disasters actually occur which is at the most local level. Thereby, the CDRI offers a tool to understand the strengths and weakness of a city, like Chennai, in order to address those adequately in future planning decisions.

This paper is structured as follows: firstly, a short theoretical understanding to the CDRI is given; secondly, the characteristics of Chennai and its ten zones and the results of the undertaken CDRI-study are given; thirdly, a conclusion gathers the key points of this paper.

2. UNDERSTANDING THE CDRI

2.1 Disaster resilience in urban areas

The term resilience used for the understanding of disaster resilient urban areas has its theoretical origin from the field of ecology where Holling (1973) described the persistence of different ecological systems to cope with disturbance and still maintain the same relationships between populations and state variables. In other words, what is the impact of a disturbance let's say lack of nutrition or changing environment on a particular species. Is it capable to bounce back from this disturbance and to what extent? This is how resilience may be understood. During the following decades several contributions (Manyena, 2006) enriched the term and began to link it to social systems, like the disaster resilience of communities (Adger, 2000; Twigg, 2007). Less specific solely on communities, Carpenter et al (2001, pp. 766) defined the resilience of a socio-ecological system as:

- "the amount of change the system can undergo and still remain within the same domain of attraction;
- the degree to which the system is capable of self-organization;
- and the degree to which the system can build the capacity to learn and adapt".

Merging the different approaches and understandings of resilience allows defining the resilience of a city in relation to climate-related disasters. While the change (Carpenter et al., 2001) or disturbance (Holling, 1973) may be replaced by clearly defined disasters (floods, storms, droughts, etc.) the system may be characterised by a complex amalgamation of different actors (communities, institutions, etc.) embedded in a physically, socially and naturally defined geographical area. Since the resilience of communities (Twigg, 2007) is defined by the cultural and social integrity of its members, a city is larger and includes more aspects than just the ability of a well-defined population to cope in the event of a disaster.

2.2 The CDRI

The previous section made clear that understanding the resilience of climate-related disasters in urban areas may be a difficult task: firstly, because resilience is understood differently depending on the source (Cutter et al., 2008) and has a close connectivity to the term vulnerability (Berkes et al., 2003); secondly, the complexity of an entire urban system to be explained in relation to resilience is cumbersome as it unavoidably must include different aspects. The World Bank (2009) has also taken an approach to offer scientific findings that cities need to become safer to disasters, but adopts a vulnerability assessment where different sectors of a city are evaluated and does not include the ability of communities in influencing the overall city's ability to respond to a disaster. This is where the CDRI fundamentally deviates from The World Bank's (2009) approach as it regards the ability of communities in shaping the resilience of a city to disasters as crucial because the ultimate aim of making cities more resilient is not just limited to the physical or infrastructural setting, but also to reduce losses in terms of human lives. Therefore, communities, or households, as it is often referred to in the CDRI, are key actors and need to be taken into account in measuring the overall resilience of a city to disasters. Similarly, the institutional ability of a city influences, as well as the natural and economic setting of a city, how a city is likely to perform in the event of a disaster. Another key difference between the CDRI and the hot-spot assessment from The World Bank (2009) lies in the conceptual and theoretical understanding of how a city's capacity can be evaluated; whereas, the hot-spot assessment uses the vulnerability approach, the CDRI uses the term resilience to identify how good a sector is performing.

Table 1: Dimensions, parameters (25) and variables of the CDRI

DIMENSIONS	PARAMETERS AND VARIABLES
PHYSICAL	**Electricity** (access, availability, supply capacity, alternative capacity) **Water** (access, availability, supply capacity, alternative capacity) **Sanitation and solid waste disposal** (access to sanitation, collection of waste: treated, recycled, collection of solid waste after a disaster) **Accessibility of roads** (% of land transportation network, paved roads, accessibility during flooding, status of interruption after intense rainfall, roadside covered drain) **Housing and land-use** (building code, buildings with non-permanent structure, buildings above water logging, ownership, population living in proximity to polluted industries)
SOCIAL	**Population** (population growth, population under 14 and above 64, population informal settlers, population density at day and night) **Health** (population suffer from waterborne/vector-borne diseases, pop. suffer from waterborne diseases after a disaster, access to primary health facilities, capacity of health facilities during a disaster) **Education and awareness** (literacy rate, population's awareness about disasters, availability of public awareness programmes/disaster drills, access to internet, functionality of schools after disaster) **Social Capital** (population participating in community activities/clubs, acceptance level of community leader (in ward), ability of communities to build consensus and to participate in city's decision-making process (level of democracy), level of ethnic segregation **Community preparedness during a disaster** (preparedness (logistics, materials, and management), provision of shelter for affected people, support from NGOs/CBOs, population evacuating voluntarily, population participating in relief works)
ECONOMIC	**Income** (population below poverty line, number of income sources per household, income derived in informal sector, % of households have reduced income due to a disaster) **Employment** (formal sector: % of labour unemployed, % of youth unemployed, % of women employed, % of employees come from outside the city; % of child labour in zone) **Household assets** (households have: television, mobile phone, motorized vehicle, non-motorized vehicle, basic furniture) **Finance and savings** (availability of credit facility to prevent disaster, accessibility to credits, accessibility to credits for urban poor, saving practice of households, household's properties insured) **Budget and subsidy** (funding of DRM, budget for DRR sufficient, availability of subsidies/incentives for residents to rebuild houses, alternative livelihood, health care after a disaster)
INSTITUTIONAL	**Mainstreaming of DRR and CCA** (mainstreaming of CCA and DRR in: zone's development plans, ability (manpower) and capacity (technical) to produce development plans, extent of community participation in development plan preparation process, implementation of disaster management plan) **Effectiveness of zone's crisis management framework** (existence and effectiveness of an emergency team during a disaster: leadership, availability of evacuation centres, efficiency of trained emergency workers during a disaster, existence of alternative decision-making personnel) **Knowledge dissemination and Management** (effectiveness to learn from previous disasters, availability of disaster training programmes for emergency workers, existence of disaster awareness programmes for communities, capacity (books, leaflets, etc.) to disseminate disaster awareness programmes (disaster education), extent of community satisfaction from disaster awareness programmes) **Institutional collaboration with other organisations and stakeholders, during a disaster** (zone's dependency to external institutions/support, collaboration and interconnectedness with neighbouring zones, zone's cooperation (support) with central corporation department for emergency management, cooperation zone's ward officials for emergency management, zone's institutional collaboration with NGOs and private organisations) **Good governance** (effectiveness of early warning systems, existence of disaster drills, promptness of zone body to disseminate emergency information during a disaster to communities and transparency of zone body to to disseminate accurate emergency, capability of zone body to lead recovery process)
NATURAL	**Intensity/severity of natural hazards** (floods, cyclones, heat waves, droughts (water scarcity), tornados) **Frequency of natural hazards** (floods, cyclones, heat waves, droughts (water scarcity), tornados) **Ecosystem services** (quality of city's: biodiversity, soils, air, water bodies, urban salinity) **Land-use in natural terms** (area vulnerable to climate-related hazards, urban morphology, settlements on hazardous ground, amount of Urban Green Space (UGS), loss of UGS) **Environmental policies** (use of zone level hazard maps in development activities, extent of environmental conservation regulations reflected in development plans, extent of implementation of environmental conservation policies, implementation of efficient waste management system (RRR), implementation of mitigation policies to reduce air pollution)

The reasons lie in a different understanding on how different sectors (see table 1) can contribute to making a city resilient. For instance, if 95 percent of the citizen have access to electricity at home they are more likely to be informed through an early-warning information from an approaching hazard, provided they have also a radio or television, which would ultimately increase their ability to respond during a disaster. These 95 percent have to be regarded as more resilient compared to the remaining 5 percent and the goal should be to provide electricity for every citizen to reach full resilience. Now, why is the use of the term vulnerability not very useful? While vulnerability is defined through the sensitivity and exposure of a system (Pelling, 2003), the outcome of a study based on the 'negative' aspects of a city may fail to adequately address and link the different linkages between the aspects. In other words, looking at the only 5 percent who have not access to electricity may fall short of looking at the potential of the much bigger number of citizen who actually are connected and are likely to respond in favour of the 5 percent during a disaster. And finally, the CDRI only includes climate-related disasters.

Thus, the CDRI consists of five dimensions which are again defined by 5 parameters each, total 25, to define the resilience of climate-related disasters in urban areas. Table 1 shows not only the five dimensions (physical, social, economic, institutional, and natural) but also their defining parameters and variables. The parameters are again consisting of five variables each to define it in more detail.

The selection of all these dimensions, parameters, and variables is based on extensive literature review and lessons learned from previous disasters and shall not be discussed further in this paper. However, concepts originating from Wisner et al. (2004), like the PAR-model, or linkages drawn among the communities and the city they live in provided by Pelling (2003), apart from earlier mentioned authors such as Adger (2000), Carpenter et al. (2001), Cutter et al. (2008), Godschalk (2003), Holling (1973), Klein et al. (2003), or Twigg (2007), served in developing the CDRI.

3. ADOPTING THE CDRI AT THE MICRO-LEVEL IN CHENNAI

3.1 Characteristics of Chennai

Chennai is located at the Bay of Bengal in the south-eastern part of Chennai and shall be seen as a coastal city which was hit hard during the Asian tsunami in 2004. Most parts of Chennai lie just a few metres above sea-level and in some areas the ground-water level even reaches the surface hampering the draining-off of rainwater, particularly after heavy rainfall events. The city is, however, experiencing only a few such events and mostly during the post-monsoon period between October and December (Revi, 2008). Also, the occurrence of heat waves and droughts are rare and if they take place then during the dry season from April to June. Nevertheless, in view of the likely change of the climate leading to more frequent and intense climate-related hazards (IPCC, 2007), the city may become more vulnerable over time to such hazards demanding adequate and wise planning decisions for the future.

As climate change is likely to become a factor which cannot anymore be neglected in planning decisions, the population growth over the last decades has changed Chennai into a city where the infrastructure, ecosystem and quality of life are reduced. Particularly, after reaching independence in the late 1940s Chennai grew rapidly and due to this, urban poor settlements began to mushroom along canals and rivers of the city (Chennai Master Plan, 2008). As a result, in 2001 around 18.9 percent of the population lived in slums.

Since the population growth has largely taken place in the central and coastal parts of the city area during the previous decades, the population is now rising in the urban fringe. This is particularly relevant for understanding the results followed by the CDRI study assessing the ten administrative zones of Chennai; whereby, zones 2, 3, 6, and 7 form the old part of the city and the remaining six zones the new part within the total 176 sq/km of the city area. Accordingly, the old part is currently experiencing population growth rates of 0.48 percent per year compared to 2.54 percent in the newer parts (Chennai Master Plan, 2008). In 2001, the population was around 4.2 million, but is likely to have risen up to 5.5 million by today. It is expected that Chennai will become almost a megacity (9.9 million) by 2025 (UNDESA, 2010).

3.2 Methodology and approach

Table 1 shows the content of a comprehensive questionnaire which consisted of total 125 variables equally divided into parameters and dimensions, as mentioned earlier. In order to include the local context certain variables were slightly adjusted to the conditions in Chennai. The CDRI questionnaires were then distributed to all the ten administrative zones to be filled-out between January and February 2010. Due to the simple structure of the CDRI where each dimension, parameter, and variable consist of the number five, a simple formula named weighted mean was adopted to also include weightings given for each variables and parameters, see figure 1 showing the calculation of a parameter:

Weighted Mean:

$$\frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} = \frac{w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5}{w_1 + w_2 + w_3 + w_4 + w_5}$$

Figure 1: Formula – Weighted Mean for calculating a score of a parameter

Scaling-up this calculation for a single parameter up to the dimension-level the overall resilience scores can be derived which is between 1 (low resilience) and 5 (high resilience).

3.3 Results

The results are shown in figure 2 and depict that the northern part (zones 1-3) of Chennai is overall less resilient than the southern or western parts of the city which is due to lower economic and natural resilience scores. The northern parts suffer disproportionally from low employment opportunities and also have to absorb the environmental impacts from solid waste disposal facilities, a large coal-fired power plant and the port. The benefits from these installations is turning out to be rather negative and lowering the resilience of the northern part of

Chennai. The highest or most resilient zone is number 7 which is also the centre for commercial activities besides of large residential areas.

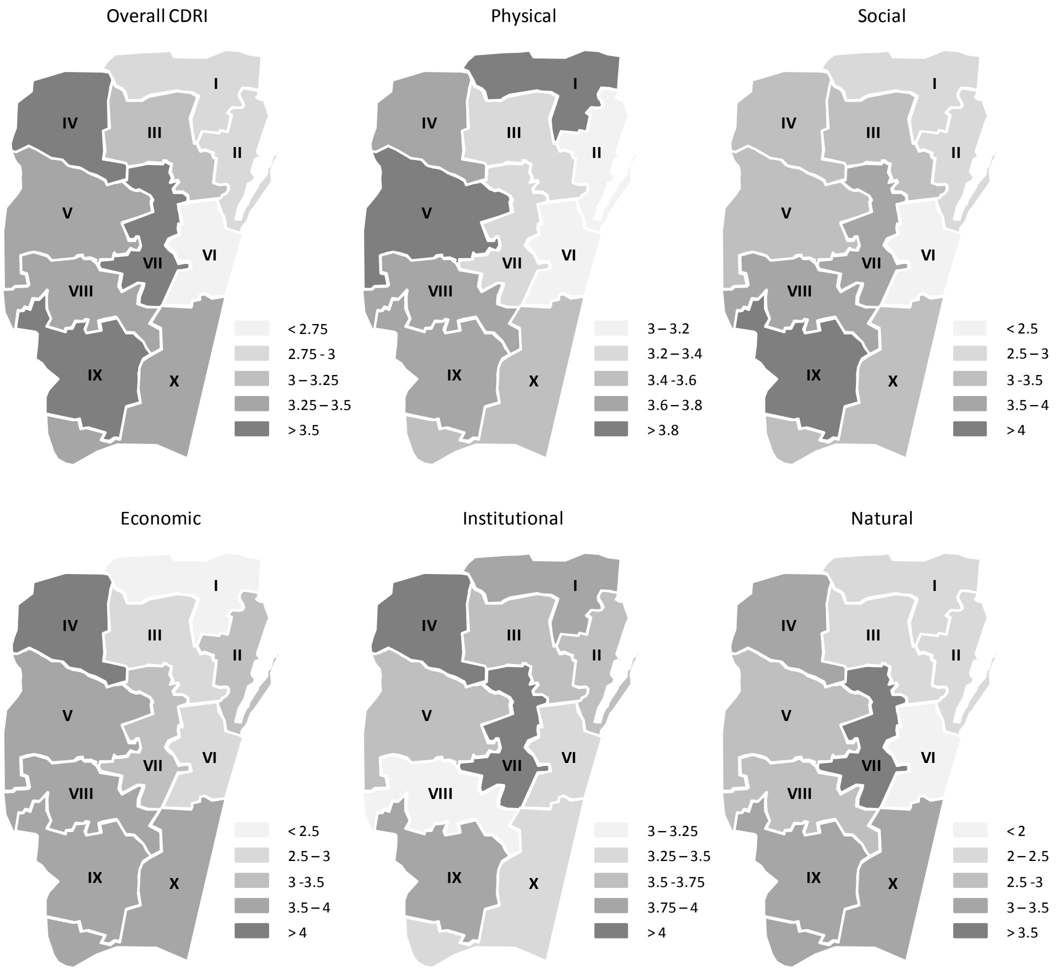

Figure 2: CDRI Results

The southern and western part form the newer part experiencing not only larger population growth, but also in terms of economic development compared to the older part, as big companies ranging from the IT sector to car manufacturing have settled in these areas. The results of this change are visible in a higher economic and overall resilience of the southern and western parts of Chennai. The institutional resilience is the strongest dimension among the five and also the one with smallest variations between the zones resilience scores. This is not surprising, but rather confirms the administrative purpose of the zone to carry out public works at a lower institutional level than the central Corporation administration. The social resilience is not showing a clear picture whether certain areas are more stronger than others, this is again not surprising since the land-use of Chennai (Chennai Master Plan, 2008) is quite mixed and does not have only industrial, commercial or purely residential areas.

The interpretation of the results is obviously not final after these explanations above, but shall point out some of the key findings and the potential of the CDRI. To add one more feature of the CDRI, the equal weighting of each parameter allows ranging the strongest and most resilient down to lowest/least resilient, as table 2 shows.

Table 2: Average city-wide CDRI scores of all 25 parameters, highest to lowest

Electricity	4.87
Institutional collaboration	4.09
Accessibility of Roads	4.05
Health	3.89
Crisis Management	3.86
Good governance	3.64
Household assets	3.54
Mainstreaming	3.45
Community preparedness	3.44
Finance and savings	3.43
Housing and land-use	3.43
Education and awareness	3.33
Water	3.24
Knowledge dissemination	3.24
Intensity/severity of hazards	3.21
Employment	3.20
Budget and subsidy	3.17
Income	3.15
Environmental policies	3.15
Social capital	2.88
Sanitation and Solid Waste Disposal	2.77
Land-use in natural terms	2.73
Ecosystem services	2.65
Population	2.60
Frequency of hazards	2.49

Table 2 emphasises that since electricity is centrally provided and at a full level for all citizens it is also close to fully resilient, unlike the population parameter, for instance, which ranks at the second-last position due to the ongoing rapid urbanisation in the newer parts of the city and the densely populated character of the city where in many zone more than 30,000 people live per sq/km.

The results from the zone-wise applied CDRI can be summarized, as follows: firstly, resilience to disasters is varying from zone to zone and is not uniform throughout the city; secondly, population growth does not correlate negatively to the physical condition of the city, as many newer parts have high resilience.

4. CONCLUSION

The CDRI offers an ideal tool for the local government and associated stakeholders to look at the weakness and strengths of the city regarding the resilience to climate-related disasters. It offers a micro-level analysis highlighting differences in resilience levels depending on the population density of an area, current population growth, economic opportunities, natural condition, etc. This is particularly relevant to target the identified 25 key sectors at the most local level as suggested by various authors to reduce the risk of disasters (Satterthwaite et al., 2007; UNISDR, 2010). Furthermore, action and planning decisions can be targeted specifically for a particular area and sector. And this is also the next challenge followed by this CDRI study, which offered a baseline assessment of the city's resilience related to different dimensions, to identify solutions enhancing the resilience to climate-related disasters. For this, a second study is ongoing where all the 155 Councillors of the city are requested to decide on the feasibility and appropriateness of pre-defined resilience enhancing actions. Since the Corporation of Chennai is about to enlarge its city area up to 426 sq/km by 2011 this study may lose its significance, however, it may serve as an indicating study from which the new added areas may benefit. On the other hand, cross-cutting studies are again needed to see how the new areas are going to merge with the current parts of Chennai along the urban fringe.

Finally, this study may also serve the Corporation of Chennai's efforts to meet some of the ten essentials defined in the 2010-2011 World Disaster Reduction Campaign: Making Cities Resilient to which it has formally committed itself.

REFERENCES

Adger, W.N. (2000) 'Social and Ecological Resilience: Are They Related?'. Progress in Human Geography. 24(3). pp. 347-364.

Berkes, F., Colding, J., Folke, C. (2003) Navigating Social–Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press. Cambridge.

Carpenter, S., Walker, B., Anderies, J.M., and Abel, N. (2001) 'From Metaphor to Measurement: Resilience of What to What?'. Ecosystems. 4. pp. 765-781.

Chennai Metropolitan Development Authority (CMDA) (2008) Second Master Plan For Chennai Metropolitan Area, 2026. CMDA, Chennai.

Cutter, S.L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., Webb, J. (2008) 'A place based model for understanding community resilience to natural disasters'. Global Environmental Change. 18. pp. 598-606.

Godschalk, D.R. (2003) 'Urban Hazard Mitigation: Creating Resilient Cities'. Natural Hazards Review. 4(3). pp. 136-143.

Holling, C.S. (1973) 'Resilience and Stability of Ecological Systems'. Annual Review of Ecological Systems. 4. pp. 1-23.

Intergovernmental Panel on Climate Change (IPCC) (2007) 'Summary for Policymakers' In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press. Cambridge.

Klein, R.J.T., Nicholls, R.J., and Thomalla, F. (2003) 'Resilience to natural hazards: How useful is this concept?'. Environmental Hazards. 5. pp. 35-45.

Manyena, S.B. (2006) 'The concept of resilience revisited'. Disasters. 30(4). pp. 433-450.

Pelling, M. (2003) The Vulnerability of Cities: Natural Disasters and Social Resilience. Earthscan. London.

Revi, A. (2008) ‘Climate change risk: an adaptation and mitigation agenda for Indian cities’. Environment and Urbanization. 20(1). 207-229.
Satterthwaite, D., Huq, S., Pelling, M., Reid, H., and Romero-Lankao, P. (2007) Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Countries. Human Settlements Climate Change and Cities Discussion Series 1. IIED. London.
The World Bank (2009) Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters. The World Bank. Washington.
Twigg, J. (2007) Characteristics of a Disaster-resilient Community: A Guidance Note. DFID Disaster Risk Reduction Interagency Coordination Group. Benfield.
United Nations (2010) World Urbanization Prospects: the 2009 Revision. United Nations Population Division, Department of Economic and Social Affairs (UNDESA). United Nations. New York.
United Nations International Strategy for Disaster Reduction (UNISDR) (2005) Hyogo Framework for Action 2005-2015. United Nations. Geneva.
United Nations International Strategy for Disaster Reduction (UNISDR) (2007) Words into Action: A Guide for Implementing the Hyogo Framework. United Nations. Geneva.
United Nations International Strategy for Disaster Reduction (UNISDR) (2010) A Guide for implementing the Hyogo Framework for Action by Local Stakeholders. United Nations. Geneva. Consultation version.
Vale, L., and Campanella, T. (2005) The resilient city: How modern cities recover from disaster. Oxford University Press. New York.
Wisner, B., Blaikie, P., Cannon, T., Davis, I. (2004) At Risk: Natural Hazards. People’s Vulnerability and Disasters. MIT Press. Cambridge.

CLIMATE DISASTER RESILIENCE OF DHAKA CITY CORPORATION- A MICRO LEVEL ANALYSIS

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ABSTRACT

Along with the threat of climate change and its induced disasters, rapid urban growth is leading to unplanned urbanization, high population density and environmental degradation of Dhaka. Already the severity of climate disaster, especially flooding is increasing. Also it is forecasted that among the coastal mega-cities Dhaka would be the most vulnerable to climate change. In this context this research intends to measure the existing level of climate disaster resilience of Dhaka City Corporation by assessing the problems and potentialities in different sectors.

Climate Disaster Resilience Index (CDRI) of 10 different zones of Dhaka City Corporation has been measured by this research. Results imply that the CDRI scores ranges from 2.4 to 3.1 in a 5 point rating scale. Out of 10, 7 zones have obtained medium level of score in CDRI. The planned residential areas have relatively higher level of climate disaster resilience; while, old parts of the city and densely populated low income areas have low level of resilience than other areas. It is expected that by utilizing CDRI results in future policy formulation and development plan disaster risk and challenges could be minimized and development opportunities could be enhanced and finally these would lead to have a resilient city in future.

Keywords: Dhaka, climate, disaster resilience

1. INTRODUCTION

Explosive growth and high density of population, low stages of economic growth and poor state of environment in many developing countries are contributing to aggravate cities vulnerabilities, enhancing disaster risk and thus reducing their climate disaster resilience (Razafindrabe et. al, 2009 and Roy, 2009). Present context of urban growth and development trend of Dhaka is a real reflection of these circumstances. For being the distinct primacy in the national urban hierarchy, Dhaka is the hub of administrative, political, economic, industrial, cultural, educational and research activities of Bangladesh. But unfortunately, among the coastal mega-cities Dhaka, the capital of Bangladesh would be the most vulnerable to climate change (Worldwide Fund for Nature 2009).

On the other hand, with an urbanization rate of over 2.5 % Dhaka is considered as one of the fastest growing cities in the world in recent decades (Roy, 2009 and Hossain, 2006). It is noticed that the recent rapid urbanization of Dhaka is taken place in lowlands, which serve as retention ponds during flooding seasons and most of the natural drainage and canals that used to drain excessive water are encroached (Rahman, 2010 and Dewan, 2004). It is claimed that urbanization has marked effects on global and local environmental conditions including climate change (Grimm, 2000, cited in Dewan et. al. 2009). In case of Dhaka already flooding has become a common environmental problem and its severity is increasing. In fact, Dhaka is historically located on the flood plain with a large number of canals and rivers bounded and crossed away. Therefore, by virtue of its topographical condition along with rapid urbanization Dhaka would be one of the worst victims of climate related disasters, especially flood. In these circumstances, for the overall economic growth and development of the country it is needed to manage these problems efficiently and enhance Dhaka’s climate disaster resilience.

Initiatives aim to enhance climate disaster resilience of a city require detail and careful assessment of its current level of vulnerabilities and resilience. During such assessment and initiatives it is important to bear in mind that there are large differences in risk and vulnerability within urban areas (Satterthwaite, Dodman and Bicknell, 2009). It is natural that a city, especially a larger city like Dhaka, covers a large and often physiographically heterogeneous area, with different exposure and susceptibility to hazards. Furthermore, population of a city and the condition under which they live are diverse. For instance, out of 10 administrative zones of Dhaka, some are old settlement with densely populated, located in the low-lying flood prone areas, some are newly developed areas. Similarly, land uses of some zones are dominated by commercial uses and some are residential. Therefore, some parts and people of a city may be more vulnerable than others (Klein et. al., 2004). In fact, city forms different micro climates within it due to the variation of land use, settlement pattern, functions, density, characteristics of residential areas and the communities live their. All these diversities contribute to disaster risk and which in turn affect human development and resilience of different parts of the city (ISDR).

Recognizing the diversity within a city and its impact on vulnerabilities and resilience, it is a foremost requirement to assess the strength, weakness, opportunities and threats of micro zones of a city. It is advised that for well governed urban center it is necessary to know the location specific, place specific needs through strong local information (Satterthwaite, Dodman and Bicknell, 2009). But there are a number of studies and initiatives addressing different aspects of Dhaka's resilience and climate, disaster vulnerabilities considered the whole city as a single unit; while, neglecting the issue of zone level diversities and its implication to resilience. However, Hyogo Framework for Action has emphasized to recognize the importance and specificity of local risk pattern and trends (ISDR, 2007) before any attempt of disaster risk reduction. In this context, this paper is an attempt to depict the micro level variations of climate-disaster resilience of Dhaka through Climate Disaster Resilience Index (CDRI).

2. METHODOLOGICAL APPROACHES OF CLIMATE DISASTER RESILIENCE INDEXING

2.1 Questionnaire/Data Collection Sheet

The questionnaire used for data collection to assess the level of climate disaster resilience is comprised of five different dimensions named Physical, Social, Economic, Institutional and Natural. Under each dimension there are five different parameters (e.g. under physical dimension, electricity, water supply, accessibility to roads etc. are parameters) and each parameter consists of five different variables (questions). Therefore, the questionnaire is treated as 5x5x5 matrix. There are total 125 questions to assess climate disaster resilience (CDR). Answer of each question is limited within the choice of 1 to 5, which means 5 point rating scale has been used to assess the resilience level, where 1 means the worst situation and 5 means the best.

2.2 Approach of Data Collection and Analysis

Data has been collected from each of the micro level administrative and functional unit of Dhaka City Corporation. This unit is known as zone. For data collection the researchers directly approach to the officials (generally higher level, relevant officials) working at the zone level of City Corporation. Through direct interview of relevant officials (sometimes individual official and sometimes group of officials in a mini workshop) answer of 125 questions were collected and also the weight to the parameters and variables were assigned. Data analysis and formulation of Climate Disaster Resilience Indexing have been done using Excel software.

3. DHAKA CITY CORPORATION: BASIC FACTS

3.1 Location and History

Dhaka City is located at the center of Bangladesh. It is placed between $24^0$40' N to $24^0$54'N latitudes and $90^0$20' E to $90^0$30' E longitudes. In 1864, Dhaka was established as Municipality. After the independence of Bangladesh in 1971, it was declared as the capital of Bangladesh. In 1978, Dhaka Municipality was awarded as the status of Corporation and finally in 1990 Dhaka Municipal Corporation was renamed as Dhaka City Corporation (DCC). At that time DCC was divided into 10 zones to decentralize its administrative and functional duties (DCC website, 2010). During the period of a history of over 400 years Dhaka has experienced not only a number of dramatic historical events but also continuously faced dynamic changes in its physical, social, economic, institutional and natural environments.

3.2 Area, Population and Population Density

Different sources have different estimation regarding the area, population and population density of Dhaka City Corporation (DCC). The website of DCC shows that the area of DCC is 360 km^2, which accommodate 8 million people (estimated in 2004) with a density of 22222 persons per km^2. Bangladesh Bureau of Statistics (BBS, 2001) estimated the area of DCC as 276 km^2 with a population of 5.3 million and the population density is 19, 286 per km^2. It is said the population density of DCC is more than double of the mega city average.

4. DISASTER RISKS OF DHAKA

Dhaka, being the primate city of the country, has dominance in terms of population share, economic contribution, trade and commerce, politics, administration and even environmental degradation. Eventually, the city is continuously facing different challenges and opportunities. In addition with numerous environmental problems and challenges, recurrent natural disasters, especially annual flooding is one of the most concerning issues of Dhaka. The main cause of floods in Dhaka city is the rise in water levels of the rivers bordering the city during monsoon season (Faisal, et. al, 2003). Dhaka is surrounded by distributaries of two main rivers, the Brahmaputra and Meghna. All sides of Dhaka city are bounded by rivers and cannels; river Buriganga is on the south, Turag on the west, Tongi Khal (cannel) on the north and the Balu and Shitalakhya rivers on the east (Hossain, 2008). In addition with the rise of river water, internal drainage congestion and in coordinated operation of flow regulation structures make the flood situation worse. Since rainfall intensity is increasing, the extreme event such as floods, drainage congestion and water logging becoming a regular occurrence in rainy season. The severity of such occurrence is increasing year on year due to climatic change and change in human activities. Rapid and unplanned urban growth of Dhaka city causing serious encroachment of natural drainage and retentions areas and eventually worsening the natural flow of water and causing serious water logging and flooding almost every year in recent decade. Infrastructures, utilities, livelihood, trade and commerce and public health all sectors are badly affected and vulnerable to recurrent flooding and water logging of Dhaka (Alam and Rabbani, 2009).

Scholars claim that beside, floods/drainage congestion, Dhaka will be affected through heat stress due to climate change. Dhaka may face ‘heat island’ problem because the temperatures of the city are a few degrees higher than the surrounding areas. Vehicle exhaust emission, industrial activities, increase of built up areas, loss of open spaces and increasing use of air conditioning are contributing to heat generation of Dhaka and this situation will continue in future (UNEP, 2005, Alam and Rabbani, 2009).

Since rapid pace of urbanization, compounded with ever-increasing population burden significantly increase urban vulnerability to natural disasters, Dhaka's disaster risk is remarkably increasing. Therefore, reduction of disaster risk and eventually building climate disaster resilience of Dhaka is an urgent need for the development and prosperity of the whole country.

5 CLIMATE DISASTER RESILIENCE OF ZONES

After being familiar with Dhaka City Corporation (DCC) by knowing about its location, area, population, environmental challenges and disaster risk (in section 2 and 3), now in this section the status of climate disaster resilience of DCC would be presented. This section highlights the level of climate disaster resilience of DCC from overall and from physical, social, economic, institutional and natural perspectives. This section also identified the different development sectors and issues (parameters/variables) that are significantly correlated with each other. Furthermore, the development sectors (parameters) and issues (variables) that have been prioritized to enhance climate disaster resilience of each zone have been listed here.

5.1 Overall Resilience

Climate disaster resilience scores of each of 10 zones have been presented as Climate Disaster Resilience Index (Overall CDRI) in Fiureg.1. This Overall CDRI is the average of the scores that each micro level area (zone) has obtained in physical, social, economic, institutional and natural dimensions.

Climate Disaster Resilience Index (CDRI) from overall perspective reveals that among the 10 zones CDRI scores range from 2.4 to 3.1. Since 5 is the highest score, these scores of Overall CDRI denote the low/poor to medium level of resilience. It is interesting to notice that the planned residential areas (Zone No. 6, 9 and 10) have relatively higher level scores in climate disaster resilience index; while, old parts of the city (except Zone No.2) and densely populated low income areas located in the fringe areas have low level of resilience scores than other areas.

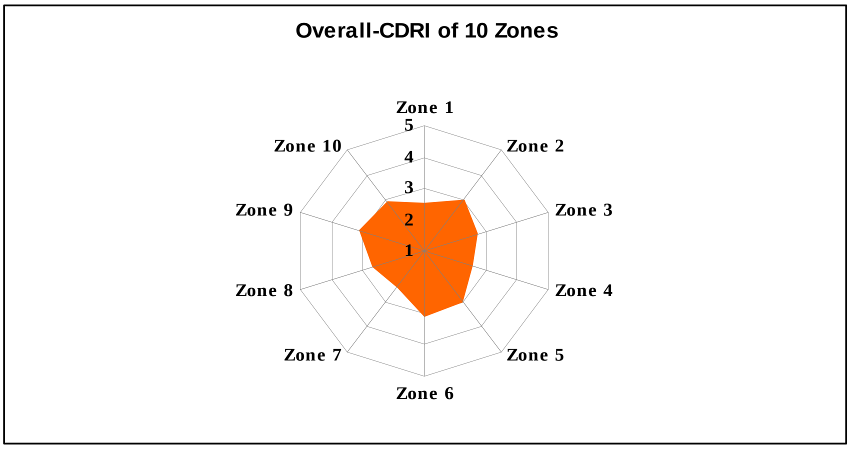

Figure 1: Climate Disaster Resilience of 10 Zones from Overall Perspective (CDRI scores)

In the overall CDRI assessment only 3 zones (no. 2, 6 and 9) have obtained the scores that are considered as good in Climate Disaster Resilience Index (CDRI). Though these three zones are part of Dhaka City Corporation and many characteristics are similar to other zones there are few features that has made these zones identical. For instance, zone 2 is the smallest zone is DCC (3 sq. km.) but accommodates the highest number of people per square kilometer. The density of this area is 125423 per sq. km., which is extremely high. In spite of having high density, being old part of city, zone 2 has obtained relatively higher score in overall CDRI. In fact this zone is located in high land, free from flooding; it is place of old residents of the city and also place of rich traditional business man of the city. As a result, relatively higher scores in physical, social and economic dimensions have lifted this zone to good position in overall CDRI. On the other hand, it is really interesting to notice that Zone No. 6, which is the location of National Parliament and residential areas of parliament members and Zone No. 9, which is the diplomatic zone and location of all embassies have relatively higher score in physical, economic, institutional and natural dimensions and eventually have obtained higher scores in overall CDRI.

5.2 Resilience in Five Different Dimensions

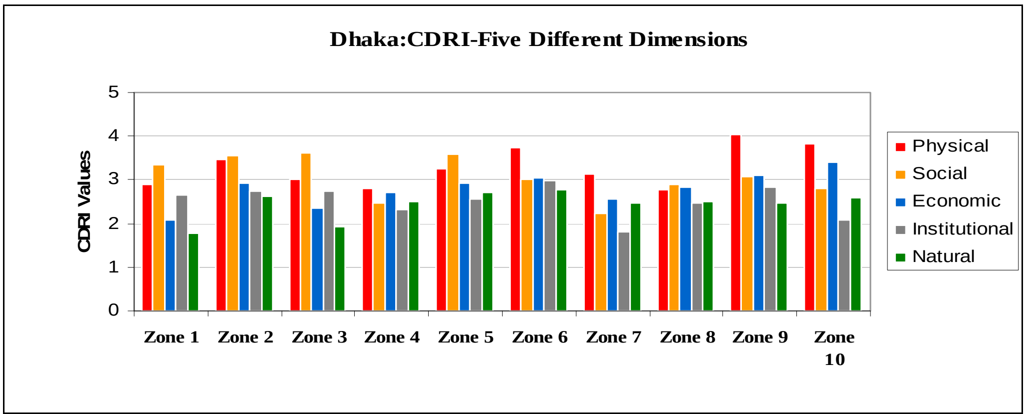

Figure 2: Climate Disaster Resilience Levels of 10 Zones in Five Different Dimensions

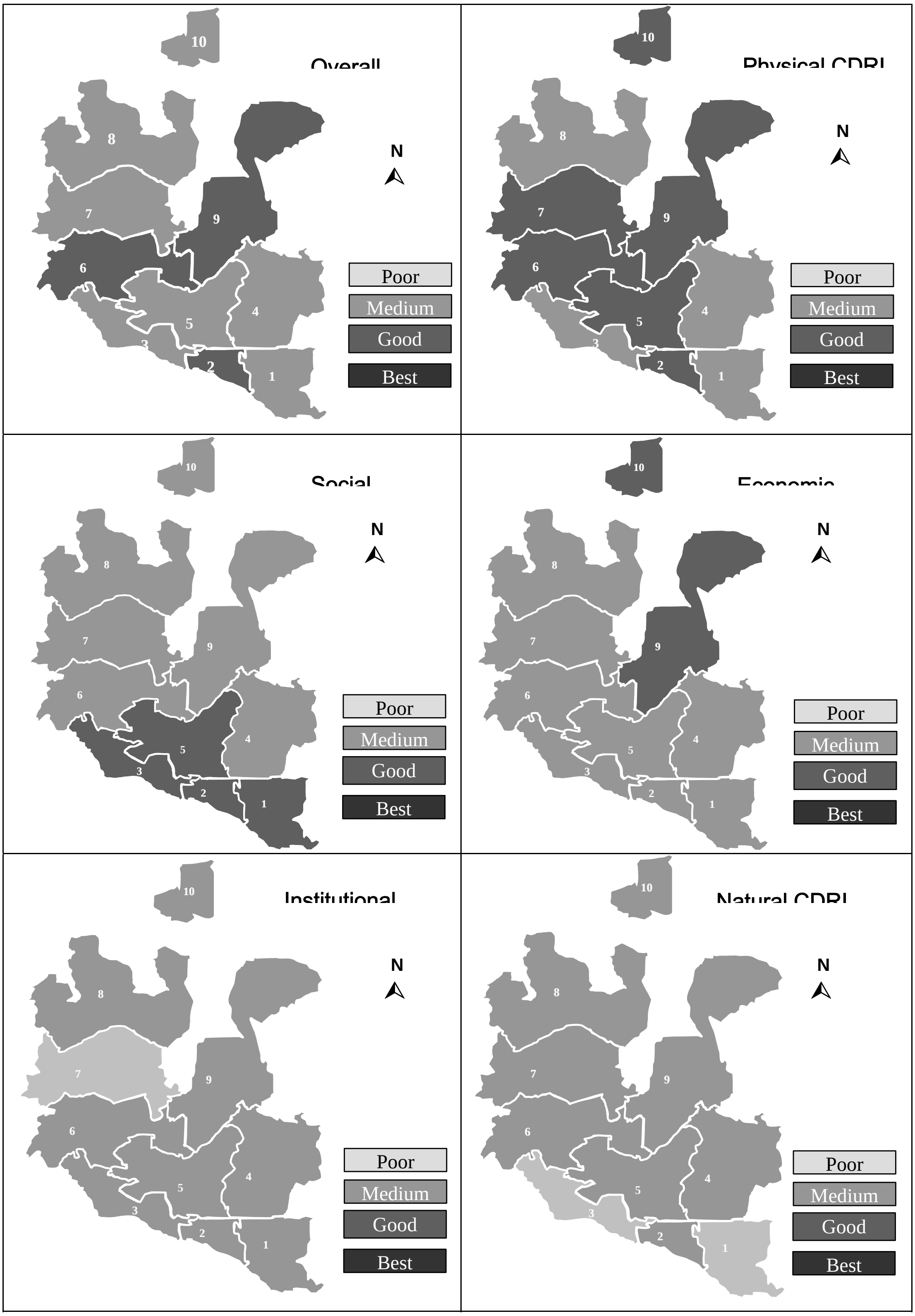

Figure 3: Dhaka City's Map Showing the Resilience Level of Different Zones in Different Dimensions.

Note: Here CDRI scores 1-2=poor, 2.1-3 = medium, 3.1-4= good and 4.1-5 = best resilience level

Physical CDRI

In Dhaka, Zone No. 9, 10 and 5 which are planned residential for higher income group have relatively better condition in almost all variables of physical dimension and achieved higher score in Physical-CDRI. Main part of zone 6 is the planned residential area for middle and higher income people. Besides this, national parliament and the residential area for parliament members are located in zone 6. Therefore, physical conditions, like accessibility of roads, land use and housing and electricity and water supply conditions are relatively better in zone 6 and thus it assessed as good in physical resilience against climate disaster. In fact, following building code and house with ownership, accessibility of roads is higher in all these planned areas. For being diplomatic area, zone 9 does not face interruption in electricity and water supply, which is most common in other areas. So, zone 9 got the highest score (4.03) in physical dimension. It should be noted that this score is the highest among all the CDRI scores in all dimensions. In the case of zone 2 and 7 though these are not planned areas they have considered as good in physical resilience (score 3.14 and 3.47 respectively). Rather electricity and water supply, housing land use and accessibility of road have contributed to this score. These areas, houses are not constructed by following building code but houses with ownership, houses above the flood level and free from polluted ground are higher, which contributed to have relatively higher scores in physical CDRI.

Interruption in electricity and water supply is severe in zones that have low score in physical CDRI, especially zone no. 4 and 8. Further, most of the buildings are constructed without building code.

Social CDRI

Social CDRI scores ranges from 2.2 to 3.6, which denote medium to good level of climate disaster resilience in social perspective. Out of 10 zones only 4 zones have been considered as good and rest 6 zones are medium. Zone No. 7 has got the lowest score and Zone No. 5 has the highest score. Contrasting with physical dimension, the social CDRI scores are relatively higher in the Zone No. 1, 2, 3, which are densely populated old parts of Dhaka. In the case of Zone No.1, 2 and 3, among different factors, social capital like community participation, acceptance of community leader and ethnic interlink are playing role in availing higher score in social dimension of CDRI. Similarly community's support during emergency and relief works, supports from NGO/CBOs and religious group are also better in these zones and it has contributed to their social resilience. In fact, these are the old parts of city, where a large number of residents are living for a long time and they have strong community feelings. Unlike Zone 1, 2 and 3, in case of Zone No. 5 social issues like health, education and awareness have contributed much to be good in social CDRI. Besides these, compare to the other planned residential areas zone no. 5 is relatively old area established in 1950s. Therefore, this zone has higher level of community participation and ethnic interlink.

Zone No. 4 and 7 are poor in the score of social CDRI. Here also social capital, community preparedness and health status playing role for their low score. Zone 4 is the principal central business district of Dhaka and Zone 7 is mixed of residential and commercial areas. Due to flood (in zone 4) and water logging (in zone 7) about one fourth of the population of these two zones suffers from water borne diseases, which is less in other areas.

Economic CDRI

CDRI scores in economic dimension implies medium to good level of resilience against climate disaster. These scores varies from 2.1 to 3.4 and out of 10 zones only two have been found as good and rest 8 are medium in economic CDRI. In economic dimension also Zone No. 9 and 10 have obtained the higher scores (3.11 and 3.41 respectively). It is said earlier that these are planned residential areas for higher income group. So from income, employment and household assets perspectives these zones are in a good position. This is very identical to inform that in both of these zones about 40% of the households have motorized vehicles, which is very low in other zones. Furthermore, in these two zones slum population is very low, which is about 10 %. In contrast, Zone No. 1 and 3, which got the lowest scores (2.1 and 2.4 respectively) are the most densely populated poor areas of Dhaka. Most of the slums are located here and more than 40% of the population lives below the poverty line. Here, income, employment and household assets are the prime factors for their low scores in CDRI Economic.

Institutional CDRI

In the institutional perspective all zones are assessed as having medium level of climate disaster resilience, except Zone No. 7. Institutional CDRI scores ranges from 1.8 to 3, which reveal poor to medium level of resilience. Here it should be noted that only zone 7 got institutional CDRI score less than 2, which denotes poor resilience. In the institutional dimensions of CDRI, Zone No. 6 and 9 present themselves as better position compare to rest other zones. Though these zones are also in the group of medium level of resilience they have obtained the scores 3 and 2.8 respectively. In contrast, Zone No. 7 and 10 assess themselves as in the lower position among the 10 zones. In fact, the mainstreaming of disaster risk reduction and climate change and the overall management of disaster are handled centrally by City Corporation. In spite of this, in the aspect of effectiveness of zone's crisis management framework, knowledge dissemination, institutional collaboration and good governance some zones evaluate them as medium to good position and some zones (like 7 and 10) as poor. This assessment has ultimately determined the CDRI score in institutional dimension.

Natural CDRI

Among the all five dimensions of CDRI assessment, natural dimension has the lowest scores in case of all zones. Natural CDRI scores vary from 1.8 to

2.8 that mean poor to medium level of resilience. These scores show that Zone 1 and 3 are in the poor condition and rest 8 zones are in medium level of resilience. Zone 1 and 3 are the place of poor communities of the city. More than 50 % areas of these two zones are very vulnerable to climate related hazards. Both of these zones face severe flood and water logging almost every year. Apart from this, the air, soil and water quality is considered as poor in these zones. Zone No. 3 is the place of tannery industries and zone 1 is a place of city bus terminal, water terminal and different types of small industries. Therefore, overall environmental condition is poor in these zones. Moreover, high density, poor housing condition and very low level of green spaces have made these zones poor in natural dimension of CDRI. Here it should be noted that though other zones are treated as medium in the natural CDRI during rainy seasons water logging condition is severe in some zones, especially Zone No 4 and some parts of 9. Ecosystem and environmental condition are also not so sound in all over Dhaka city.

6. CONCLUSION

Climate Disaster Resilience Index (CDRI) analysis of Dhaka City Corporation (DCC) measures the capacity of city's infrastructure and services to withstand against disasters and evaluates how the communities and institutions within a city are expected to deal with such an event. By examining the problems, potentialities, strengths and weakness of 10 different zones of City Corporation this study assesses the ability of each zone to absorb, maintain and recover (bounce back) from a hazardous situation.

Assessment results reveal that climate disaster resilience score of different zones ranges from 2.4 to 3.1 out of 5, which imply poor to medium level of resilience. It has been noticed that the planned residential areas, which is the place of medium to higher income groups and relatively new part of the city (zone 9, 10 and 6) have the higher scores in overall climate disaster resilience. These zones also have higher scores in physical and economic dimensions of climate disaster resilience, while climate disaster resilience in social perspective is comparatively lower than the old part of the city. Zone 1, 4 and 7 have obtained overall CDRI scores ranges from 2.4 to 2.5, which are the lowest. Zone 1 and 4 are the two most densely populated areas of Dhaka and place of a large number of slums and squatters. These two zones are also highly vulnerable to flooding and water logging. In contrast, though the population density of zone 7 is lower than zone 1 and 4, it is also vulnerable to water logging. The institutional dimension of this zone is scores the lowest. Coupled with this lowest level of institutional resilience, low scores in social, economic, natural dimensions of climate disaster resilience contributed zone 7 to be the least one in CDRI assessment.

This CDRI assessment shows that different zones have different level of climate disaster resilience. Since zones differ from locational and functional characteristics, their problems, vulnerabilities and potentialities are different. Eventually, the resilience level differs from zone to zone. Therefore, different zones need to have zone specific development plan, programs and different sectoral priorities to enhance their climate disaster resilience. But the regretting fact is zone has neither any power nor the ability to prepare development plan addressing their local problems and needs. However, in 1990 Dhaka City Corporation was divided into 10 zones with a view to decentralize the administration. Every zone has an office for administration and there are about 10 sub departments to operate and manage administration and development activities within the zone. But there is no cell or department to handle or manage disaster risk. Any sort of development plan and program formulation is solely done by the central authority of City Corporation. Even though, at the central level too there is no specific plan for disaster management. Since the Standing Order of Disaster (Govt. order) has the provision of constitution of Disaster Management Committee at City Corporation level, DCC has formed this committee and these committee has some prescribed duties to perform before, during and after any disaster.

It is claimed that from the perspective of climate change fast growing cities pose difficult challenges for local Government (Roy, 2009). Therefore, recently Government of Bangladesh has published the National Plan for Disaster Management 2008-2015 and this plan recommend for the preparation of City Corporation Disaster Management Plan for each city. So it is expected that in near future DCC will prepare its disaster management plan. This Disaster Management Plan of Dhaka City Corporation should incorporate zone specific disaster management plans, where this CDRI analysis would be an important guideline. It is expected that CDRI outcomes would facilitate to formulate location specific, need and problem specific future policy, hazard mapping, disaster management plan and budget allocation and finally overall development plan implementation. Thus climate disaster resilience of each zone would be enhanced, which would lead to have a resilient city in future.

REFERENCES

Alam, Mozaharul and Rabbani, Golam, MD., 2009. Vulnerabilities and Responses to Climate Change for Dhaka. in Satterthwaite, David, Dodman, David and Bicknell, Jane (editors), *Adapting Cities to Climate Change-Understanding and Addressing the Development Challenges*, Earthescan, London. 93-110.

BBS, 2001. *Statistical Year Book of Bangladesh*, Bangladesh Bureau of Statistics, Ministry of Planning, Government of Bangladesh.

Dewan, Ashraf, M. and Yamaguchi, Yasushi, 2009. Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Applied Geography*, Vol. 29, Elsevier Ltd. 390-401.

Dewan, A.M., Nishigaki, Makoto and Komatsu, Mitsuru, 2004. DEM based Flood Extent Delineation in Dhaka City, Bangladesh, *Journal of the Faculty* *of Environmental Science and Technology*, Vol. 19, No.1. Okayama, University, Japan. 99-110.

Dhaka City Corporation Website, http://www.dhakacity.org/, accessed on May 5, 2010.

Faisal, I.M., Kabir, M.R. and Nishat, A., 2003. The Disastrous Flood of 1998 and Long Term Mitigation Strategies for Dhaka City. *Natural Hazards*, Vol. 28, Kluwer Academic Publishers, Netherlands. 85-99.

Hossain, Shhadat, 2008. Rapid Urban Growth and Poverty in Dhaka City. *Bangladesh e-Journal of Sociology*, Vol. 5, No.1. 1-24.

Hossain, Shhadat, 2006. Rapid Mass Urbanization and Its Social Consequences in Bangladesh: The Case of The Megacity of Dhaka. Paper presented in 16th Biennial Conference of the Asian Studies Association of Australia in Wollongong, June 26-29, 2006.

ISDR, 2007. *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters, International Strategy for Disaster Reduction*, United Nations, Geneva.

Klein, Richard J.T., Nicholls, Robert, J. and Thomalla, Frank, 2004. Resilience to Natural Hazards: How useful is this concept? *Environmental Hazards*, Elsevier Ltd. 35-45.

National Plan for Disaster Management 2008-2015, 2008. published by Disaster Management Bureau, Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh.

Rahman, Anisur, Md., 2010. Dhaka's Peripheral Development and Vulnerability to Earthquake Liquefaction Effects, *Asian Disaster Management News*, Vol. 16, No. 1, Asian Disaster Preparedness Center.6-7.

Razafindrabe, Bam H.N., Parvin, G.A., Surjan, A., Takeuchi, Y., Shaw, Rajib, Climate Disaster Resilience: Focus on Coastal Urban Cities in Asia, *Asian Journal of Environment and Disaster Management*, Vo.1, No. 1, Research Publishing Services, Singapore,101-116.

Roy, Manoj, 2009. Planning for sustainable urbanization in fast growing cities: Migration and adaptation issues addressing in Dhaka, Bangladesh, *Habitat International*, Vol. 33, Issue 3, Elsevier Ltd. 276-286.

Satterthwaite, David, Dodman, David and Bicknell, Jane, 2009. Conclusions: Local Development and Adaptation. in Satterthwaite, David, Dodman, David and Bicknell, Jane (editors), *Adapting Cities to Climate Change-Understanding and Addressing the Development Challenges*, Earthescan, London, 359-383.

UNEP, DoE and BCAS, 2005., *Dhaka City- State of Environment 2005*, Department of Environment (DoE), Ministry of Environment and Forest, Government of the People's Republic of Bangladesh in collaboration with United Nations Environmental Programme (UNEP) and Bangladesh Center for Advance Studies (BCAS).

World Wide Fund for Nature, 2009. *Mega-Stress for Mega Cities, A Climate Vulnerability Ranking of Major Coastal Cities in Asia*, WWF International, Switzerland.

CLIMATE AND DISASTER RESILIENCE OF DELHI, INDIA

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ABSTRACT

The study addresses disaster risk of Delhi through resilience approach. The Climate Disaster Resilience Index (CDRI) tool is used to assess resilience level of the city against climate related hazards. The city resilience level is assessed through various dimensions: physical, social, economic, institutional, and natural. The study is community based and was conducted in all nine revenue districts of Delhi. They are: Central Delhi, North Delhi, South Delhi, East Delhi, North East Delhi, South West Delhi, New Delhi, North West Delhi, and West Delhi. The data was collected from district disaster management cells across all nine districts of Delhi. The result shows that New Delhi is the most resilient district due to its physical, social and economic factors, whereas East Delhi is the least resilient district due to physical and natural factors. The limitation of the study is exclusion of geological and biological hazards. Moreover, the questionnaire contains some subjective assessment. The study only considers climate related hazards to assess resilience score. However, the approach is distinct in itself by showing the strength and weakness of districts by assessing their resilience level against climate related disasters.

Key words: climate related hazards, disaster risk, resilience, assessment, and districts

1. INTRODUCTION

India is one among the most vulnerable country to natural hazards like floods, droughts, cyclones and earthquakes. According to National Disaster Management Authority of India, 40 million hectares of land is prone to flooding, 18.6 million of land flooded annually, 18% percent of total area is prone to drought, 60% of sown area is drought prone, and approximately 50 million people are annually affected by drought (NDMA, 2009).

Since 1981, more than 300 disasters have occurred in India (EM-DAT, 2010). Most of them are hydrometeorological in nature like storms, floods, mass movement (wet), extreme temperature, droughts, and wild fire. Followed by geophysical disasters like earthquake, volcano, mass movement (dry), and finally, Biological disasters such as epidemics, insects, infection and stampede. The number of people killed due to hydro meteorological disaster is also higher than geophysical and biological disasters. The total number of persons killed is 115,342. Out of this 12% percent were killed due to biological disasters, 43% from geophysical and remaining 49% killed from hydrometeorological disasters. However, over 98% of people are affected by hydrometeorological disasters and 2% affected by geophysical disasters (EM-DAT, 2010). This shows that the impact of hydrometeorological disaster caused heavy damage to people and their property in the recent past.

The urban centers in India are often characterized with "rapid population growth, high densities, poverty, and high differentials in access to housing, public services and infrastructure" (Revi, 2008). These characteristics are the main factors that increase the vulnerability to natural and man made hazards in cities. Moreover, the impact of disasters in city is unevenly distributed. For example, people from upper and middle income groups cope well with disasters and recover faster due to stable employment, insurance, credit and assets. On the other hand, people from low income group or poor in the same city are severely affected due to fewer assets, lack of insurance, few diversity income and sources (Vatsa, 2004). The main reason for this uneven distribution of impact of disasters is rapid pace of urbanization, which often leads to increase in the population of the city due to heavy influx of migrants. The urban poor are considered as migrants, who come to city due to push factors like unemployment, low standard of living and also due to push factors like better economic opportunities and education (Niebergall et al., 2006). Most cities mainly grow in hazard prone areas like in the river bed or near coast areas. This makes poor settlements at risk. They are at risk not due their location near hazard prone areas, but also due to their socio-economic conditions like poor housing, poor education, low standard of living, and mainly engaged in informal sectors (Sherbinin et al., 2007). They are the most vulnerable when disaster strikes (Benson and Clay, 2003). They are the mostly frequently killed, injured or lose their house after any disaster (Albala-Bertrand, 2003). It is also believed that the impact of climate change will further shrink their coping capacity to withstand against the climate related disasters.

The study aims at addressing disaster risk of Delhi through resilience approach. It is community based approach and data is collected from District Project Officers (DPOs) and Project Coordinators (PCs) across all nine districts of Delhi. The city is highly populated and vulnerable to climate related hazards like, heat waves, cold waves, floods, and drought (water scarcity).

The first section describes the challenges of disaster risk in Delhi. The second section focuses on how disaster risk is addressed in Delhi and why Climate Disaster Resilience Index (CDRI) approach is effective for dealing with disaster risk. The third section describes analysis of the study, which was conducted in Delhi using CDRI approach. Finally, the last section describes the significance of the outcome.

2. DISASTER RISK IN DELHI – CHALLENGES

After independence the city has grown up in a haphazard way. It is among the cities with million plus population. The rapid pace of urbanization leads to massive growth of slums followed by misery, poverty, unemployment, exploitation, inequalities, degradation in quality of life. The city is vulnerable to natural and man made disasters: Flood, Earthquake, fire, epidemic diseases and terrorist attack. This section discusses the overall challenges, which increases disaster risk in Delhi.

2.1 Rapid urbanization

The city is experiencing rapid urbanization. According to 2001 Census, 93 percent of Delhi's population lives in urban areas (Ministry of Health and Family Welfare, 2007). The population increased from 0.7 million in 1947 to 13.7 million in 2001. It is expected to double by 2026 (Ministry of Health and Family Welfare, 2007). Migration is considered as one of the main reason for urban population growth. The city experienced large scale migration from north eastern states of India. As per census 2001, 0.2 million migrants move into Delhi every year. The reason for high migration is the pull and push factors. These factors force them otherwise attract them to come to the city for employment. The rapid increase in the expansion of industry created huge employment opportunities. In 1951, there were 8160 small scale industries, which increased to 129000 in 2001 (Government of Delhi, 2006). The rapid migration created huge pressure on basic amenities, which led to inequality in living standard. For example, housing shortage; inadequate water and sanitation services; poor solid waste management; pressure on public transportation; power failure; air, water, and noise pollution. The next section discusses the environment degradation.

2.2 Environment degradation

The environment condition in Delhi is very poor. The last three decades led to change in the land use pattern. There is increase in the built up area. In 1990-91, the built up area was 742 sq. km, which was 50% of geographic area of Delhi. It increased to 897 sq. km (60.5%) in 2000-2001 (Government of Delhi, 2006). This was due to the huge expansion of industries, which attracted large migrants to city for jobs. High rate of urbanization and migration in the past has deteriorated the environment condition of the city. Environment was degraded due to change in the land use, explicit use of ground water, discharge of waste affluent in the river, high density, water pollution, air pollution and noise pollution. The condition of water and sanitation is very poor. In 2001, 25% of households had no access to piped water supply and faced shortage of 200 Million Gallon Daily. Yamuna river is considered as one of the most polluted river in the world (Rahman et al., 2007). Similarly, air pollution and noise pollution have contributed to environment degradation.

2.3 Climate related hazards

The city is vulnerable to climate related hazards like floods, heat waves, and water scarcity. In the recent past, Delhi has experienced flooding. Floods are mainly caused due to river and local flooding. Since 1900, floods took place in 1924, 1947, 1976, 1978, 1988 and 1995. High magnitude floods occurred in 1977, 1978, 1988 and 1995 (DDMA, 2009). These floods have caused heavy damage to life and property. In 1977 flood, crop damage was close to one million rupees. Similarly in 1988 flood, 8,000 families were affected (DDMA, 2009).

2.5 Increase in the slums, and squatter's population

As per 2001 census, the slum population of the city was 15.7 percent of total population, which was 1.85 million (Government of Delhi, 2006). It increased to 3 million in 2004. The number of housing units are 0.6 million, which accommodate 3 million population. That means more than three persons living in one room. Apart from this, there are 50,000 to 70,000 persons, who are homeless (Government of Delhi, 2006). The living condition in slum areas is very poor due to absence of basic services such as street light, sanitation, water and road network. These situations often threaten health. Approximately 25 percent of slum settlements have access to drainage system and only 30 percent have toilets and bath facilities. The problem of inadequate access to water supply is very common in slum areas. These type of population remain in high risk not due to their poor socio – economic condition but also due their settlement in vulnerable locations like near sea coast, low lying area etc. The next section discusses the approach for addressing disaster risk.

3. ADDRESSING DISASTER RISK IN DELHI

3.1 Existing approach

The existing approach to for addressing disaster risk is based on hazards and vulnerability analysis (DDMP, 2009). The disaster risk of each districts is calculated using formula (i.e. Risk = Hazard * Vulnerability). This approach is far better than approaches, which were centered only on the hazard aspects. Here, the vulnerability aspect considers physical, social, and economic conditions, which are important in risk creation. The current approach analyzes vulnerability from the weakness or limitation of the system or group, which is essential but incapable to show the ability or capability. According to Westgate and O' Keefe 1976, vulnerability can not measured without referring to the capacity of the population to absorb, respond and recover from the impact of the event. In other word, the existing approach does not recognize the positive aspect of population in calculating the risk.

3.2 Current adopted approach for this study

The study uses approach that addresses risk from the resilience concept. Resilience is capacity of population to absorb, respond, and recover from the impact of events or disasters (Westgate and O' Keefe, 1976). The concept of resilience is applied to urban area. The concept of resilience was first evolved in ecology and used by Holling in 1973. Thereafter, the concept received huge attention and used in the many fields, including hazards and disasters. Timmerman was probably the first, who use "the concept of resilience to in relation to hazard and disaster" (Klein, 2003).

Climate Disaster Resilience Index (CDRI) tool is used to assess the resilience level of Delhi's districts against climate related natural hazards. The tool consists of five dimensions, namely physical, social, economic, institutional and natural. Each dimension contains five parameters. For instance, Physical dimension consist of five parameters, such as electricity; water; sanitation and solid waste disposal; accessibility of roads; and housing and land use. Each of these parameters consists of five questions/variables. Therefore all in all, there are 125 questions and resilience level of district is assessed based on 125 questions. This approach is holistic in nature and by no mean is an exhaustive assessment. In addition, after end of parameters and dimensions, the respondent is asked to rank or assign weight to each parameter and dimension in order to reflect the priority of the districts. The collected data is analyzed using Weighted Mean Index (WMI) and Aggregate Weighted Mean Index (AWMI) to compute the resilience score for each parameter and dimension respectively. The resilience score varies from one to five. One shows very poor resilience score and five shows very high resilience score. High resilience score reflects higher preparedness to cope with climate related disasters and vice versa. Finally, the total score will show the strength and weakness of the districts.

3.3 Disaster Resilience of Delhi - About the study and outcome

The study was conducted in nine revenue districts of Delhi. They are: Central Delhi, North Delhi, South Delhi, East Delhi, North East Delhi, South West Delhi, New Delhi, North West Delhi, and West Delhi. The data collection was done using Climate Disaster Resilience Index (CDRI) questionnaire. The data was collected from district disaster management cell across all nine districts of Delhi. The respondents were District Project Officer (DPO)s and Project Coordinator (PC)s who look after the disaster management activities in their districts. The study assesses resilience level of each district on the basis of five important dimensions: physical, social, economic, institutional, and natural. The following section discusses the outcome of the study for each dimension.

3.3.1 Physical resilience of nine districts of Delhi

The physical resilience of nine districts is assessed on the basis of five variables including electricity; water; sanitation and solid waste disposal; and housing and land use. The physical resilience shows that New Delhi district is most resilient district among all nine districts, where as East Delhi district is the least resilience district (Fig 1). The main reasons for very low resilience is due to poor sanitation and solid waste disposal, then low level of housing and land use, and water. Approximately, 463 tons of solid waste is produced every day and out of which 299.36 is disposed properly (Rahman et. al, 2007). District high population is also a major factor for huge solid waste generation. The district is also characterized by

poor housing and land use. Most of the houses are without ownership. Almost 80 percent of district area suffers from interruption in water supply.
On the other hand, Electricity, water and accessibility of road are the three important factors that makes New Delhi most resilient district. The district has separate municipal body, which mange civic services. The interruption in the water and electricity is very less in comparison to other districts. The district roads are broad and accessible during normal flooding. All roads have roadside covered drain. Entire district has pave roads. The district is characterized with parliament house, Supreme Court, central government ministries, Delhi high court, and union service public commission.

3.3.2 Social resilience of all nine districts

The social resilience of nine districts is assessed from five variables including population; health; education and awareness; and social capital. Over all, the resilience level of all nine districts is between medium to good. However, New Delhi is the most resilient districts among all nine districts (Fig. 1). The population density of this district is lowest among all districts, which is 5117 per. Sq. km in 2001 (Planning Department, 2009). Similarly, the total population is also lower than other districts, which 171806 in 2001 (Planning Department, 2009). Moreover, there are other factors that are reason for high resilience including health, community preparedness, social capital, and education and awareness. Therefore, people suffer less from water and vector born diseases every year. On the other hand, North east district is the least resilient district among all districts (Fig. 1). The population density is highest among all nine districts, which is 29, 468 persons per sq. km. in 2001 (Planning Department, 2009). More over, the population growth rate annually is also highest among all districts, which is more than 6% in 2001. (Planning Department, 2009). The high density also reflects on health aspect. Certainly, due to high density of population, the health aspect is between poor to medium. Population, health, and social capital are three most prominent factors responsible for low resilience of North East district.

3.3.3 Economic resilience of all nine districts

The economic resilience of nine districts is evaluated from five variable factors namely income; employment; household assets; finance and savings; and budget and subsidies. The most resilient district is New Delhi (Fig. 1). The main factors responsible for high resilience level are: income, employment and household assets. The district is a mix of commercial activities as well as institutional areas where government offices are situated. Most of them living in this district are engaged in formal jobs. Due to better income, people are well equipped with household assets. The residences in this district are better off in finance and saving.
Central Delhi is the least resilient district among all nine districts (Fig. 1). The main factors responsible for low resilience are: income, employment, and finance and saving. Most of the working population in this district is engaged in household industries. The working population is 35% of the total population (DDMPa, 2009). The dependency ratio is 1.88. There are certain areas in this district, where dependency ratio is 2 (DDMPa 2009). Many household have only one earner. According to 2001 census, up to 70 percentage of population of central Delhi lives in slums area (Ministry of Health and Family Welfare, 2007).

The resilience scores for budget and subsidy is same in all nine districts. Equal budget is distributed among all districts for disaster risk reduction related activities.

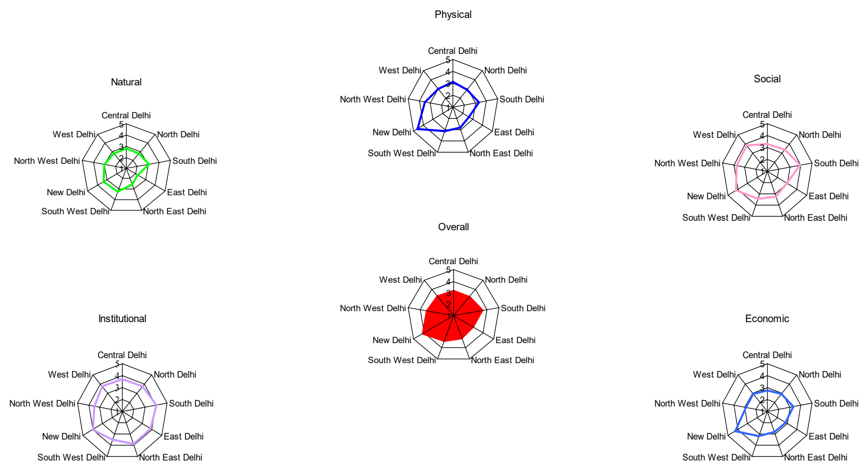

Figure 1: CDRI graph of all nine districts of Delhi

3.3.4 Institutional resilience of all nine districts of Delhi

The institutional resilience is measured by five variables including mainstreaming of disaster risk reduction and climate change adaptation; effectiveness of crisis management framework; knowledge dissemination and management; institutional collaboration with other organizations and stakeholders; and good governance. The institutional setup is common for the nine districts. All districts follow common guidelines laid down by the National Disaster management Authority (NDMA) and Delhi Disaster Management Authority (DDMA). The resilience level of all districts is between medium to good (Fig. 1). However, the mainstreaming of disaster risk reduction and climate change adaptation is not visible in all nine districts. All districts use some common platform and tools for disseminating information about disaster preparedness. For example, books, leaflets, manpower and campaign etc. All districts have same collaboration with state organization, Municipal bodies, and with other districts. The district bodies are dependent on each other as well as on urban local bodies at state level. The early warning system clearly disseminates all information related to disaster to all nine districts.

3.3.5 Natural resilience of all nine districts

The natural dimension is evaluated from five variables: intensity and severity of climate related hazards; frequency; eco system services; land use in natural terms; and environmental policy. New Delhi is the most resilient district in natural terms (Fig. 1). There are three most prominent factors that are responsible for high resilience: intensity and severity of climate related hazards, frequency, and land use in natural terms. The district is not vulnerable to flood. Moreover, it is less vulnerable to heat waves and water scarcity. The frequency of heat waves and water scarcity is once in a year. The land use in natural term is good. The district land has no settlements located on hazardous ground. The district has well maintained gardens, trees etc. The least resilient district is east Delhi (Fig. 1). The main factors contributing towards low resilience are: intensity and severity of climate related hazards, eco system services, and land use in natural terms. The district is highly vulnerable to flooding due to its location near Yamuna River. The land use pattern shows that the district area is mostly occupied with densly populated area. There is no green space left. The air and water quality in the lakes and river is very poor due to poor solid waste management.

3.3.6 Overall resilience of all nine districts

The overall resilience of nine districts is assessed through overall resilience score of each district. New Delhi is the most resilient districts among all nine districts (Fig. 1). The factors responsible for high resilience score is physical, social and economic factors. The physical resilience is high mainly due to better electricity, water and sanitation services. The district has its own Municipal body that manages civic services in the district. The main factors responsible for high social resilience are population, health and social capital. The district population is least among all nine districts and density is below 5000 person per. Sq. km. The health condition is better due to hygienic environment condition and better health facilities. The residential area in this district include large bungalow, foreign mission/ state guest houses, government colonies and private colonies.

East district is the least resilient among all nine districts (Fig. 1). The most prominent factors responsible for low resilience are: physical and natural factors. The district has low physical resilience mainly due to poor solid waste management, then housing and land use, and water. Due to high population density, the district produces large amount of solid waste, which is not often properly disposed regularly. The housing condition is very poor mainly because a large number of population lives in the proximity to polluted industries and dumping ground. The condition of water is also very poor. More than 60% of the district is affected by the interruption in water supply. The other reason for low resilience is natural factor. Due to proximity to Yamuna River, the district is vulnerable to flooding. More, than 90% of district area is densely populated. The land use in natural term is very poor. There is no green space due to built area, which is more than 90% of total district area.

4. CONCLUSION AND WAY FORWARD

The study is a significant approach in assessing disaster risk at micro level. The outcome clearly shows the strength and weakness of districts. It further throws light on the factors that are responsible for low and high resilience. For example, the important factors for low resilience for east district are: physical and natural factors. Similarly, New Delhi is the most resilient district manly due to economic, physical and social factors. Based on the above outcome, the policy points can be recommended to encourage government officials to enhance the capacity of their specific institutions, which are less resilient. The policy points aim at disaster risk reduction and received high attention at the Hyogo convention in 2005. The policy points are Hyogo Frame work for Action (HFA) task. HFA tasks include: making disaster risk reduction a priority, improving risk information and early warning, building a culture of safety and resilience, reducing the risks in key sectors, and strengthening preparedness for response. The above mentioned policy points encompass all important area to strengthen the resilience level.

4.1 Significance of the outcome

The outcome of the study helps policy or government officials as well as other stakeholders in understanding the strength and weakness of their districts. The approach is community based. So it facilitates stakeholders in assessing and enhancing the resilience of the community. It helps in reviewing their work progress. The following section discusses on outcome significance.

4.1.1 District Project Officer (DPOs) and national stakeholders

The district project officer can very well use result of this study. They study can contribute in making disaster management plans document for their district. The district plan highlights disaster risk and vulnerability of their respective area. Therefore, the study can be well incorporated into the district disaster management plan. The study also highlights key sectors or area, which requires more attention from the officials. It can also help in monitoring the effectiveness of the activities by district project officers, which are related to disaster risk reduction. For example, activities those are related to disaster preparedness, mitigation and prevention.

The outcome of the study is also useful for the local organization as well as national level organization who work in the community. For example, the development planner at national or local level can use the outcome of this study while making the development plans. The outcome is also useful for the Non government organization, in understanding the resilience level of the community, where they work.

REFERENCES

Albala-Bertrand J.M., 2003. Urban disasters and globalization. In Kreimer, A., Arnold, M., and Carlin, A. (ed) *Building safer cities: The future of disaster risk, Series 3*.The International Bank for Reconstruction and Development / The World Bank, pp 75-82

Benson, C., and Clay, E. J., 2003. Disasters, vulnerability, and the global economy. In Kreimer, A., Arnold, M., and Carlin, A. (ed) *Building safer cities: The future of disaster risk, Series 3*.The International Bank for Reconstruction and Development / The World Bank, pp 3-31

DDMA, 2009. Chapter III: Hazard and risk assessment. In *Delhi disaster management draft plan*. Accessed 28 May 2010 http://www.delhi.gov.in/wps/wcm/connect/doit_dm/draft/plan.

DDMP, 2008. *District disaster management plan – north*. Office of the deputy commissioner (north), Government of NCT of Delhi

DDMPa, 2008. *District disaster management plan – central*. Office of the deputy commissioner (central), Government of NCT of Delhi

EM-DAT, 2010. *Data Set*. http://www.emdat.be/advanced-search Accessed 26 May 2010.

Government of Delhi, 2006. *Delhi human development report 2006*. Oxford university press, New Delhi

Government of Maharashtra, 2005. *Status report - Maharashtra Floods 2005*. http://mdmu.maharashtra.gov.in/pdf/Flood/statusreport.pdf. Accessed 23 May 2010

Klein, R.J.T., Nicholas, R. J., and Thomalla, F. (2003) Resilience to natural hazards: How useful is this concept? *Environmental hazards,* 5, 35-45

Ministry of Health and Family Welfare, 2007. *State of urban health in Delhi*. www.uhrc.in/name-CmodsDownload-index-req-getit-lid-63.html. Accessed 27 May 2010

Mehrotra, S., Natenzon, C.E., Omojola, A., Folorunsho, R., Gilbride, J., and Rosenzweig, C., 2009. *Framework for cities climate risk assessment.* http://www.indiaenvironmentportal.org.in/files/FrameworkforCity.pdf Accessed 1 June 2010

Morrow, B.H., 1999. Identifying and mapping community vulnerability. *Disasters* 23(1): 1-18

NDMA, 2009. *National policy on disaster management 2009*. http://ndma.gov.in/ndma/guidelines/NationaDisasterManagementPolicy2009.pdf. Accessed 24 May 2010

Planning Department, 2009. *Chapter 3 Demographic profile. In Economic survey of Delhi 2008-2009.* http://www.delhi.gov.in/wps/wcm/connect/DoIT_Planning/planning/economic+survey+of+dehli/content+2008-09/demographic+profile Accessed 23 May 2010

Pelling M (2003) Tracing the roots of urban risk vulnerability. In Pelling M. *The vulnerability of cities – natural hazards and social resilience,* Earthscan, UK, pp 3-18

Rahman A., and Netzband M., 2007. An assessment of urban environmental issues using remote sensing and GIS techniques an integrated approach: A case study: Delhi, India' In Urban Population-Environment Dynamics in the Developing World: Case Studies an Lessons Learned. De Sherbinin, A., Rahman A., Barbieri, A., Fosto, J C., and Zhu, Y., (eds.) *International Cooperation in National Research in Demography (CICRED)*, Paris (Working paper). www.ciesin.columbia.edu/repository/pern/papers/urban_pde_rahman_etal.pdf-2009-12-04. Accessed 28 May 2010

Revi, A., 2008. Climate change risk: an adaptation and mitigation agenda for Indian cities. *Environment and Urbanization* Vol 20(1): 207-229. doi: 10.1177/0956247808089157

Sherbinin, A., Schiller, A., Pulsipher, A., 2007. The vulnerability of global cities to climate hazards. *Environment and Urbanization* Vol. 19, No.1, April 2007

Vatsa, K.S., 2004. Risk, vulnerability, and asset-based approach to disaster risk management. *International Journal of Sociology and Social Policy* Volume 24 Number 10/11 2004

Wisner, B., Blaikie, P., Cannon, T., and Davis, I., 2003. *At risk - natural hazards, people's vulnerability and disasters.* Routledge press

Status of natural hazards in the Asia-Pacific region and impacts of climate change

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ABSTRACT

The Asia-Pacific region is prone to a wide variety of disasters caused by natural hazards. According to the EM-DAT database, between 1975–2006, while the region experienced 37% of number of world's disasters and 44% of economic losses, it suffered more than 57% of total number of global mortality and 88% of the affected populations. Unfortunately, this trend has continued in subsequent years and in 2008 alone, out of the 10 worst disasters in terms of total human losses nine occurred in the Asia-Pacific region and consequently 98% of people killed by disasters worldwide were from Asia. The same year witnessed two disasters of historical dimension, Cyclone Nargis in Myanmar and the Wenchuan earthquake in China, both in Asia, causing large-scale death and destruction. Asia-Pacific region is particularly prone to climate-sensitive hydro-meteorological disasters such as floods (35%), windstorms (28%) and water-induced landslides (8%). The global distribution shows that Asia-Pacific region is accounted for more than 45% of the world's water-related disaster fatalities during the period from 1980 to 2009, and 90% of all water-related casualties. Based on the limited available data of last three decades, it is statistically difficult to quantify and isolate the exact impact of climate change on frequency of occurrence and magnitude of disaster events, considering the time dimension and randomness involved in both the climate and disaster processes. However, while comparing earthquakes and climate sensitive hydro-meteorological disasters in the region for the time period 1980-2009 using EM-DAT, it was found that the increase in the number of climate sensitive disasters is much higher than the number of earthquakes. While IPCC and UNEP present the global climate change scenarios and their implications, though scattered, there is an emerging body of evidence from the Asia-Pacific region that highlights the possible linkages between climate change and its impacts on natural hazards of the region.

Keywords: *natural hazard, disaster, EM-DAT*

1. INTRODUCTION

Natural hazards have always been part of human existence and will remain so in future, but by themselves they do not cause disasters until combined with an exposed, vulnerable and ill prepared population or community. Based on available data and information for the past 30 years (1980-2009), this presents the status of disasters and natural hazards causing them in the Asia-Pacific region. Issues related to generally improved disaster reporting mechanisms as well as neglected and unreported disasters were also examined to identify the need for review and improvement of the existing data sources and information sharing platforms at regional level. Low-intensity but high-frequency hazards have a significant overall impact on human life, livelihoods and economic assets in many developing countries of the region, but usually they are not adequately prioritized in national DRR programs as compared with the more visible or widely reported major disasters that attract international attention.

The paper is intended to serve as a rational basis for adopting a more comprehensive approach to various socio-economic and technical aspects of disaster risk reduction in the face of (i) gradually mounting evidence of climate change impacts on natural hazards, (ii) increasing human population, economic assets and infrastructure in disaster prone areas, and (iii) uneven economic development within countries (rural vs. urban) and across the region (low, medium and high income countries). Some mega-disasters overwhelm smaller countries both in terms of physical damage and economic losses, and therefore, such countries can benefit significantly from a regional platform for DRR through better sharing of data, information, and knowledge.

1.1 Regional overview of disasters, deaths, and damages

Cumulatively, the number of disaster events recorded around the world between 1900 and 2009 was over 17,000 affecting over 6 billion people, with more than 38 million fatalities. While in the year 1900 only 6 disaster events were recorded globally (ICHARM, 2009), the number of the recorded disasters in 2009 increased to 328 (EM-DAT). While 2009 appears a relatively quiet year, the number may increase further based on most recent trends as the annual average for 2000-2009 is 392. Over the period 1991-2005, disaster related economic losses were over US$ 1 trillion. The estimated financial loss due to disasters caused by natural hazards in the 1970's decade was US$75.5 billion, whereas the estimated loss during the period from 2000 to 2009 was staggeringly above US$750 billion, a ten-fold increase. Even if, inflation, purchasing power parity and other time-sensitive financial parameters are considered, almost a 1000% increase in just two decades does underscore the rising magnitude of disaster related damage. While sharp rise in disaster events can be attributed to several factors, including better reporting mechanisms and possibly climate change effect on existing natural hazards, the corresponding increase in impact is most probably due to increasing human population and associated high-value economic assets and infrastructure as well as their increasing exposure to natural hazards.

The Asia-Pacific region is prone to a wide variety of disasters caused by natural hazards. According to the EM-DAT database, between 1975–2006, while the region experienced 37% of number of world's disasters and 44% of economic losses, it suffered more than 57% of total number of global mortality and 88% of the affected populations. Unfortunately, this trend has continued in subsequent years. In 2007, 37% of disasters caused by natural hazards recorded by the EM-DAT database (EM-DAT, 2010) occurred in Asia alone accounting for 90% of all the reported victims and 46% of economic damage. In 2008, out of the 10 worst disasters in terms of total human losses nine occurred in the Asia-Pacific region and consequently 98% of people killed by disasters worldwide were from Asia. The same year witnessed two disasters of historical dimension, Cyclone Nargis in Myanmar and the Wenchuan earthquake in China, both in Asia, causing large-scale death and destruction (see Box 1). No mega-disasters occurred in 2009, the event ranking highest in death toll was the earthquake in Indonesia which killed over 1,100 people, followed by a series of typhoons and floods that caused many deaths, making Asia once again the most affected continent (CRED, 2010). In fact, six of the top ten countries with the highest number of disaster-related deaths were in Asia. The long-term disaster trends cannot be based on a single year data, considering the disastrous losses caused by the earthquakes in Haiti and China in the early 2010.

Longer-term data on disaster occurrence and impacts in the Asia-Pacific region demonstrate continuous upward trend in the moving annual average of primary disaster statistics over the last three decades (Figure 1.1.1), and it seems there is a significant jump following mega-disasters (see red line in the graph) that have occurred in recent years (Box 1). The long term averages indicate that the Asia-Pacific region accounts for 42% of the world's disasters caused by natural hazards and 65% of their victims and therefore, unsurprisingly, the region occupies the top spot in the list of world's regions for most of the disaster related indicators. For example, during the last three decades, the Asia-Pacific region had the highest average number of reported deaths per million inhabitants due to disasters.

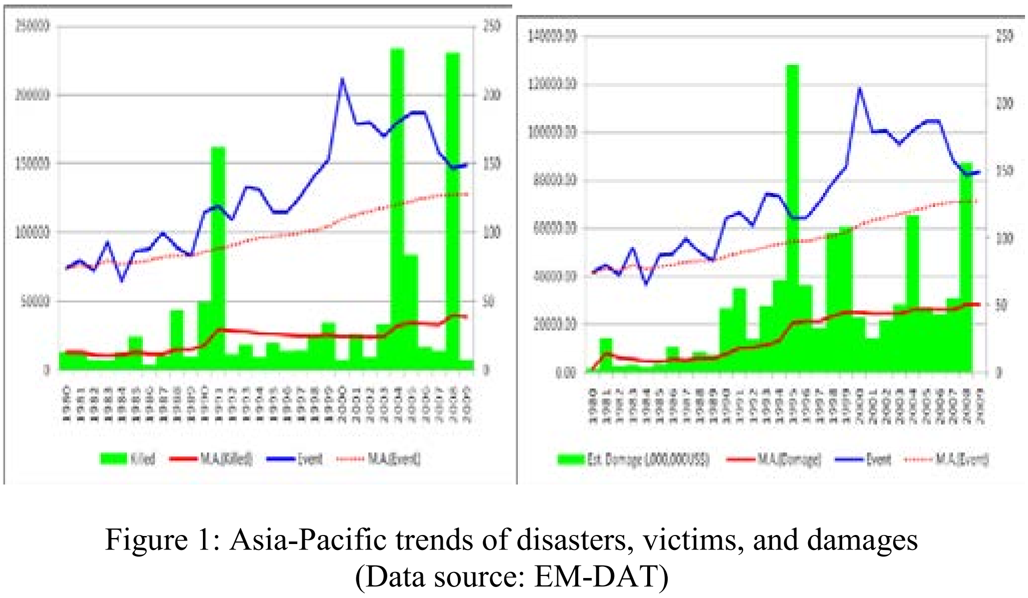

Figure 1: Asia-Pacific trends of disasters, victims, and damages
(Data source: EM-DAT)

All sub-regions of the Asia-Pacific get their share of the disasters caused by natural hazards and related impacts (Table 1.1.1). South and South-West Asia had most disasters (1,283) over a 30 year period (1980-2009), followed by South-East Asia (1,069)), and, consequently, these two sub-regions experienced greater fatalities. However, East and North-East sub-region suffers more economically and in terms of number of affected people. It should be noted that to some extent the 2004 Indian Ocean Tsunami does spike the disaster statistics of South-East Asia (see Box 1). Considering the smaller size of the Pacific sub-region, the relative loss of human life and economic damage are significantly high.

Table 1: Disasters and impacts in Asia-Pacific sub-regions over 1980-2009

Asia-Pacific Sub-region	Events (Number)	Killed (Thousand)	Affected (Thousand)	Estimated Damage (million$)
East and North-East Asia	908	162,804	2,567,214	578,602
South-East Asia	1,069	394,687	272,777	48,220
South and South-West Asia	1,283	566,423	1,914,696	141,506
North and Central Asia	297	34,644	17,231	15,636
Pacific	406	5,425	19,126	39,078
Asia-Pacific (Total)	**3,963**	**1,163,983**	**4,791,044**	**823,042**

Among the world's one thousand most fatal disasters between 1900 and 2006, floods, windstorms and droughts accounted for up to 88.5%. Over the last three decades, 76% of all disaster events were hydro-meteorological or climatological in nature; and these accounted for 45% of the deaths and 79% of the economic losses caused by natural hazards. Asia-Pacific is prone to water-related disasters such as floods (35%), windstorms (28%) and mass movement (8%) as shown in Figure 1.1.2. The global distribution shows that Asia-Pacific region is accounted for more than 45% of the world's water-related disaster fatalities during the period from 1980 to 2009, and 90% of all water-related casualties.

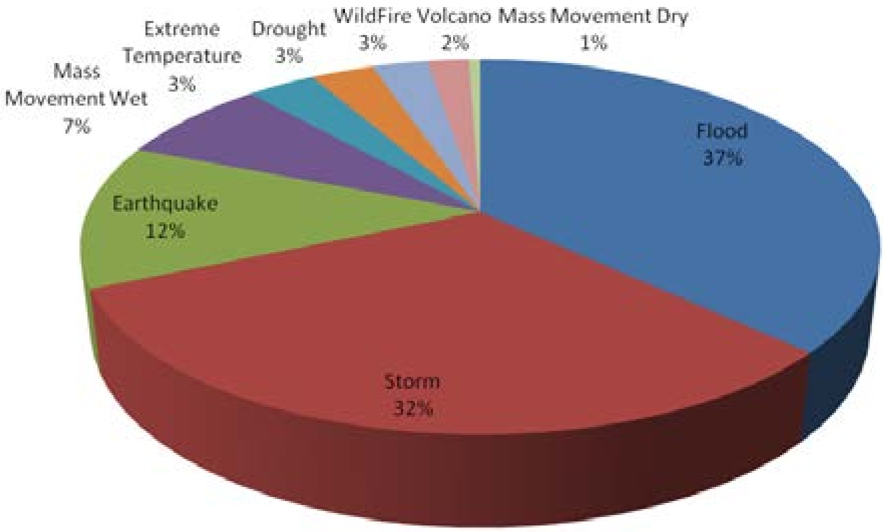

Figure 2: Distribution of disasters in the Asia-Pacific region during 1980-2009 (Source: EM-DAT)

Using EM-DAT database, Table 1.1.4 and Figure 1.1.3 compare the number of annual events and moving averages for two categories of disasters – earthquakes vs. climate sensitive hydro-meteorological disasters such as floods, drought, storms, extreme temperature, and landslides – for the Asia-Pacific region for the time period 1980-2009. It can be clearly seen that increase in the number of climate sensitive disasters is much higher when compared with the number of earthquakes. For example, in 1980, there were 11 reported earthquake disasters compared to 55 climate sensitive disasters (a difference of 44), whereas in 2009, 15 earthquakes vs. 124 climate sensitive disasters (a difference of 109). The trends demonstrated by moving average (M.A.) lines in Figure 1.1.3 also confirm a much faster increase in the number of climate sensitive disasters, with a difference of 83 in annual average of the two categories of disasters based on 30-year data. It should be clearly noted here that these trends take into account both the improved reporting mechanisms and increased exposure due to population growth, as these are at same levels for both categories of disasters under consideration.

Table 2: Comparison of decadal and 30-year (1980-2009) average annual numbers of earthquake and climate sensitive disasters for the Asia-Pacific region

Time Interval	Average Annual Number of Earthquakes (A)	Average Annual Number of Climate sensitive Hydro-meteorological disasters (B)	Difference (B – A)
1980 – 1989	10	64	54
1990 – 1999	15	94	79
2000 – 2009	19	136	117
30-year average	**15**	**98**	**83**

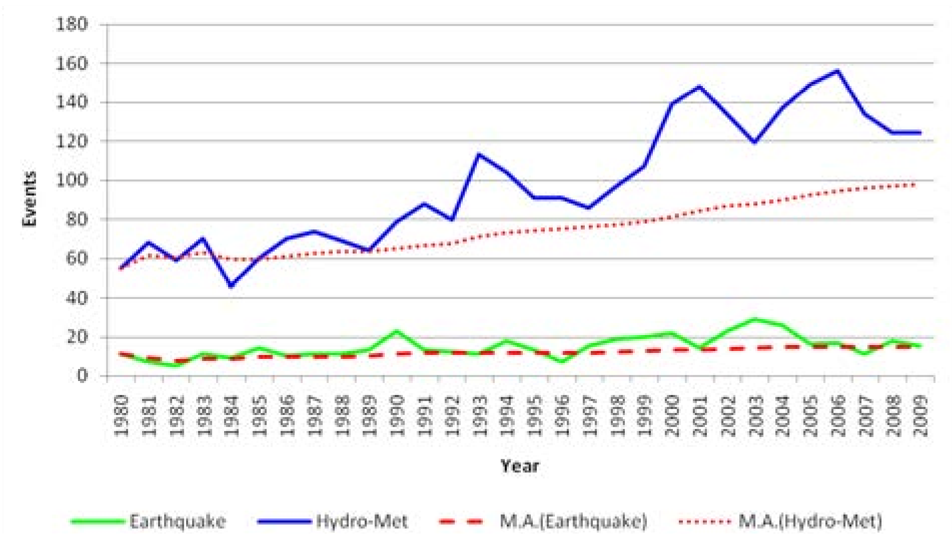

Figure 3: Comparison of moving averages of numbers of earthquakes and climate sensitive disasters for the Asia-Pacific region over the period 1980-2009 (climate sensitive hydro-meteorological disasters include floods, droughts, storms, extreme temperatures, and wet landslides, Data source: EM-DAT)

1.2 Neglected and unreported disasters in the Asia-Pacific region

The Asia-Pacific region, perhaps like any other region in the world, experiences a significant number of smaller disasters that go unreported by EM-DAT and similar international data capturing systems. Most of these are low-intensity, high-frequency disasters that often do not make headlines in international press or publications, but actually inflict serious damage to highly vulnerable populations and their livelihoods on a constant basis. Ironically, many local communities take these as an integral part of their existence and learn to live with them with varying degree of success. However, on the positive side, these long-term experiences have helped them develop indigenous knowledge and practices which need to be better documented and shared among DRR communities.

Let alone the community-based extensive disaster risk identification and reduction, many of the developing countries simply do not have modern technical and adequately qualified human resources for community level disaster monitoring programs, particularly in the rural areas where majority of the region’s population lives, and hence it never became a function of local government bodies to identify potential local hazards, map them and develop rescue, recovery and re-construction plans accordingly. The other part of the problem lies with internationally accepted individual disaster definition and reporting methodologies which are based on absolute number of deaths and economic damages due to single disaster event, ignoring the frequency of such events and their sustained impact on local communities. The aggregate impacts of such disasters are difficult to quantify based on the available data. Some examples are presented below to highlight this issue of neglected and unreported disasters and to draw attention of various DRR stakeholders for review of existing methodologies and data collection and reporting protocols and procedures at local, national, sub-regional and regional levels.

1.2.1 A comparison of EM-DAT and Desinvetar Databases

EM-DAT and Desinventer databases were examined to compare the number of disaster events from Indonesia (1998-2009) and Sri Lanka (1980-2008). In case of Indonesia, Desinventer data are available from 1998 only. Four disasters, namely floods, landslides, cyclones and droughts were considered for the analysis. Earthquakes and tsunamis were not considered, those being generally catastrophic events and well captured by both Desinventer and EM-DAT.

Table 3: Comparison of Desinventer and EM-DAT data in Indonesia (1980-2009)

Disasters	No. of Events		People Killed		People Affected	
	EM-DAT	Desinven	EM-DAT	Desinventer	EM-DAT	Desinventer
Flood	63	2,296	2,826	1,233	3,525,309	11,862,147
Lanslide	29	735	1,115	1,273	332,330	17,699
Cyclone	2	680	4	109	3,715	147,778
Drought	1	1,149	0	0	15,000	0
Total	**95**	**4,860**	**3,945**	**2,615**	**3,876,354**	**12,027,624**

In case of Sri Lanka, the total numbers of recorded disaster events in Desinventer database were 3,076 from 1980 to 2008, whereas only 49 events were recorded in EM-DAT database for the same period (Table 1.2.2). The reported number of flood events during the period was 2,210 and 39 in Desinventar and EM-DAT respectively. However, the reported the number of casualties due to flood in EM-DAT is nearly 3 times higher than that of Desinventer. Further investigations show that a large number of deaths (325 casualities) were reported in EM-DAT in 1989. A significant difference were also found in people affected by the disasters in these two datasets, but it is not as severe as in the case of Indonesia.

Table 4: Comparison of Desinventer and EM-DATA in Sri-Lanka (1980-2008)

Disasters	**No. of Events**		**People Killed**		**People Affected**	
	EM-DAT	Desinvent	EM-DAT	Desinvent	EM-DAT	Desinventer
Flood	39	2,210	933	317	9,283,426	8,445,805
Lanslide	1	293	65	490	130	52,543
Cyclone	3	41	14	9	433,000	861,235
Drought	6	532	0	0	6,006,000	7,804,286
Total	**49**	**3,076**	**1,012**	**816**	**15,722,556**	**17,163,869**

Both in case of Indonesia and Sri Lanka, the number of events reported in Desinventar is very large in comparison to EM-DAT. On the contary, the reported number of people killed in Desinventar is lower than the EM-DAT. Desinventar has reported nearly 50 times more numbers of disasters in case of Indonesia and 60 times more in case of Sri Lanka. This shows that with the present criteria in EM-DAT for data capturing does misses quite a big numbers of disaster events. Secondly, reporting of higher number of casualties in EM-DAT (although the reported number of disaters events are very low) highlights that data varification is an issue to which attention should be paid.

1.2.2 Disasters in Pacific Island Countries

Pacific Island Countries (PICs) are vulnerable to a range of natural hazards, such as cyclones, volcanic eruptions, earthquakes, floods, tsunamis, landslides and droughts. The small, highly dispersed land areas and populations, and changing nature of life in the Pacific, intensify this vulnerability. Official statistics suggest that natural hazards have a considerable economic impact on development in the Pacific. (SOPAC, 2008). The real total impact of disasters caused by natural hazards, including long-term impacts on the living conditions, livelihoods, economic performance and environmental assets of Pacific Island Countries, is likely to be much larger (SOPAC, 2008). In addition, due to the small populations, economies and land areas of many Pacific Island Countries, unreported disaster-related damages that are small relative to the damages elsewhere in the world can have a large impact relative to the country's total GDP and population.

Many small islands are affected by random cyclonic events, which are a major problem for communities, often causing significant storm damage and flooding. Storm surges have often inundated land, caused loss of life and severely damaged infrastructure in some small islands, for example, atolls in Tuvalu, the Marshall Islands, Federated States of Micronesia and the northern Cook Islands. During these events, freshwater lenses may receive considerable inputs from land inundation by seawater and subsequent infiltration, and many months may pass before they return to a potable condition. The frequency of tropical cyclones has been related to the ENSO cycle (SOPAC, 2002).

The unfortunate reality is that disasters caused by natural hazards can have a debilitating impact upon Pacific island economies. According to the World Bank (2006), disasters in the Pacific have reportedly directly affected more than 3.4 million people and led to more than 1,700 reported deaths in the region (excluding PNG) since 1950. In the 1990s alone, reported disasters cost the Pacific Islands region US$2.8 billion in 2004 terms (World Bank, 2006). However, it is only at the national level that the true impact of disasters on the economy are visible. This is because, compared to developed countries with larger reserves to draw on in times of disaster, the small size of most Pacific island states means that disaster can have a disproportionately high impact on their economy. Accordingly:

- During major disaster events, Samoa reported average economic disaster costs of 46 percent of annual GDP. (World Bank, 2006);
- The 2007 earthquake and accompanying tsunami that hit the Solomon Islands cost the country around 90% of the 2006 Government Budget (ADB, 2007);
- Cyclone Heta which hit Niue in 2004 effectively completely wiped out the national GDP, with immediate losses in 2004 amounting to over five times that of the GDP (SOPAC, 2008).

These are only the direct estimates of the costs of disasters and are based in immediate losses such as the destruction of infrastructure and crops. However, disasters also indirectly impact economic growth further by removing access to infrastructure such as inability to get produce or producers to markets and lowering economic capacity such as loss of educational opportunities.

As there has been relatively little research on broader disaster impacts in the Pacific, the true costs continue to be underestimated, creating problems in alerting policy makers and international donors to the serious economic consequences of natural hazards and the imperative for integrating comprehensive DRR into national development planning (SOPAC, 2008). Despite the serious negative impacts of disasters caused by natural hazards in the Pacific, there is no systematic collection of comprehensive data on these effects. The understanding and documentation of these effects are vital to the development of long-term policies for reconstruction, mitigation and preparedness. The lack of data also limits the scope for conducting cost-benefit analyses of DRR measures (SOPAC, 2008).

1.2.3 Tornadoes in Bangladesh

Bangladesh lies between the Himalayas to the north and Bay of Bengal to the south, and geographically characterized by an intricate river system, complex coastal configuration, and shallow bathymetry. This unique geography provides cold heavy air from the north and warm moist air from the south, leading to favorable conditions for severe thunderstorms which spawn tornadoes or other strong winds during pre-monsoon (March-May) and post-monsoon (October-November) seasons. Tornadoes are identified as one of the unpredictable localized hazards in Bangladesh which result in significant deaths and disabilities, loss of income, and destruction of resources. In recent decades, they have drawn little attention, as the emphasis on disaster management has been dominated by floods and cyclones. The frequency of tornadoes in Bangladesh is similar to that of the central United States, and is among the highest in the world. More than 10,000 deaths have been attributed to tornadoes during the period 1961 to 1996 (IAWE, 2009). Based on the number of casualties and overall impact on national economy, tornadoes and thunderstorms are now considered as one of the major hazards and exceeded only by cyclones and floods in Bangladesh. Bangladesh is making efforts to reduce the impact of such neglected localized disasters within the larger context on national disaster risk reduction and management (IAWE, 2009).

1.3 Conclusions

1) Last 30 years data demonstrate a continuous rise in occurrence of disasters caused by natural hazards in the Asia-Pacific region, economic losses/damages, number of people affected and in some cases number of people killed. The trends are more or less similar in all the sub-regions of the Asia-Pacific. Probable factors behind these upward trends include improved disaster reporting mechanisms, increase in human population, rapid economic development, and impacts climate change on hydro-meteorological processes.
2) The underlying factor for the increasing trend of casualties and damage is the high levels of absolute and relative exposures to natural hazards in all sub-regions of the Asia-Pacific.
3) Among the different types of disasters, hydro-meteorological disasters are the most frequent, causing a greater loss of human life, livelihoods and economic damages in Asia-Pacific as compared to the past. Last 30 years data confirm a much faster increase in the number of climate sensitive disasters – such as flood, drought, cyclone, extreme temperature and wet landslides – compared to the number of earthquakes which is the main geological disaster in the region. It is worth noting that these trends take into account both the improved reporting mechanisms and increased exposure due to population growth and urbanization, as the influence of these factors are same for both categories (hydro-meteorological and geological) of disasters.
4) Some countries in the Asia-Pacific region suffer significantly from neglected disasters such as tornadoes/cyclones in Bangladesh and the Pacific Island countries. A significantly large number of small but frequent disasters from Indonesia and Sri Lanka go unreported in official database such as EM-DAT, highlighting the need for review of existing diversity in disaster reporting mechanisms at national and international levels.

REFERENCES

ADB, 2007. Rehabilitation and Reconstruction Program for Disaster-affected Areas of Solomon Islands, draft.

EM-DAT (Raw Data Source www.emdat.be as accessed in May 2010)

IAWE, 2009. Proceedings of International Forum on Tornado Disaster Risk Reduction for Bangladesh - To Cope with Neglected Severe Disasters. International Association of Wind Engineering (IAEW).

ICHARM, 2009. Global Trends in Water-Related Disasters: an insight for policymakers. The United Nations World Water Assessment Progr amme: Side publications series.

SOPAC, 2002. The Pacific Dialogue on Water and Climate: Synthesis Report. Published by South Pacific Applied Geoscience Commission (SOPAC).

SOPAC, 2008. Disaster Risk Management in the Pacific: Economic Analysis and Advocacy by Paula Holland, SOPAC Secretariat, Fiji Islands.

CRED, 2010. CRED CRUNCH, Vol. 19. (www.cred.be)

World Bank, 2006. Not If But When: Adapting to Natural Hazards in the Pacific Islands Region: A Policy Note.

Sustainable Concrete for Urban Infrastructural Application

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ABSTRACT

The scarcity of natural resources and concern for environmental protection has necessitated the exploration of alternative concrete materials to sustain the development and maintenance of urban infrastructure. Towards this end, research is being carried out on concretes made without natural sand or with sand replaced by waste glass at the National University of Singapore. The fresh, mechanical and durability properties of such concretes were investigated and presented in this paper. Sandless concrete was found to possess similar mechanical properties as normal concrete. Reduced drying shrinkage and improved resistance to chloride penetration were observed in sandless concrete with cement replaced by fly ash. The mechanical properties of waste brown glass concrete were comparable to normal concrete even with sand totally replaced by waste glass particles. Also, mortar bar tests to ASTM C1260 on mortar screened from fresh waste glass concrete indicated no active aggregate-silica reaction.

Keywords: *concrete, durability, mechanical properties, waste glass*

1. INTRODUCTION

Urban infrastructure plays an important role in supporting the social and economic activities of mega-cities. Traditionally, concrete has been used as the main material for both new construction and rehabilitation works. However, the scarcity of natural resources and the need for environmental protection has necessitated the exploration of alternative concrete materials. As a result, numerous research works have been carried out globally on the use of manufactured sand and aggregates, and industrial by-products such as fly ash and blast furnace slag as replacement of cement, sand and coarse aggregates, which form the main ingredients for the production of concrete.

In view of the scarcity of concreting sand on the one hand and the low recycling rate of household waste in the city-country of Singapore, a research has been initiated at the National University of Singapore to develop concretes made without natural sand or with sand replaced by waste glass. The properties of such concretes have been investigated and are reported herein.

2. "SANDLESS" CONCRETE

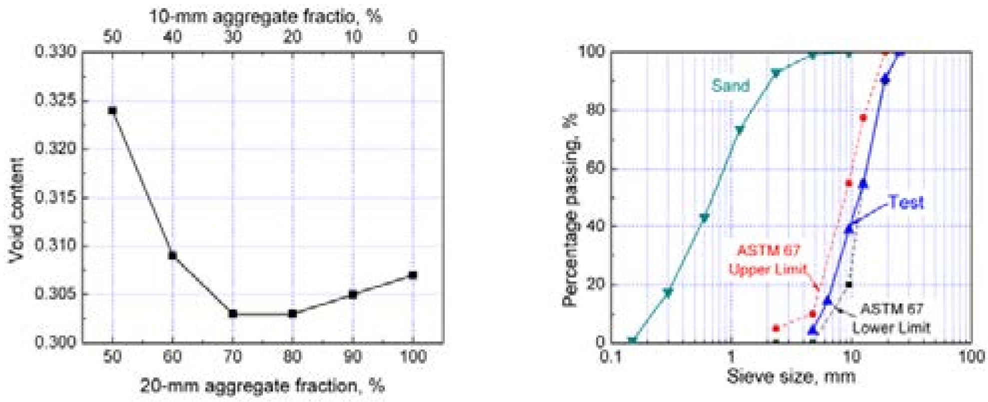
The term "sandless concrete" is used herein to refer to concrete made without natural sand. There are concretes that do not contain fine aggregates, such as no-fines concrete and pervious concrete; however, such concretes have high permeability, low unit weight and low strength, and are used mainly in minor structures or in pavements.

The present study was aimed at producing sandless concrete with a cube compressive strength of at least 30 MPa, which is required for use in reinforced concrete members. First, the mixture design was determined to achieve a densely packed concrete with minimal porosity. The water-cement ratio was then varied to produce concretes of different strengths, and the fresh properties, mechanical properties and durability of these sandless concretes were investigated.

2.1 Mixture Design

In order to produce a workable sandless concrete, the cement paste has to bind and lubricate the coarse aggregates adequately. From the economical point of view, the paste should be minimal, which requires the coarse aggregates to be densely packed. Thus, it was decided to use two coarse aggregate sizes of 10- and 20-mm in the mixture proportion so as to reduce the void content in the concrete. The voids in the aggregates for different combinations of 10- and 20-mm aggregates were determined following ASTM C29.

Figure 1(a) shows that a void content of less than 0.31 could be obtained if the volume fraction of 20-mm aggregates is between 60 and 100%. The ratio of 10- to 20-mm aggregates was thus selected as 40:60 in this study, and the corresponding aggregate size distribution is shown in Figure 1(b), which satisfies the ASTM C33 grading requirement for size 67 aggregates. The paste volume was taken to be about 10% more than the void volume, or 341 L/m^3.



(a) Void content (b) Aggregate size distribution

Figure 1: Void content and aggregate size distribution

As shown in Table 1, four groups of sandless concrete with *w/c* ratios of 0.40, 0.45, 0.50 and 0.55 were investigated. For comparison purpose, four corresponding groups of normal concrete containing natural sand were also included. The ratio of natural sand to coarse aggregates was 1:2 by mass, with the ratio of 10-mm to 20-mm aggregates remaining at 40:60 as in sandless concrete. At the same *w/c* ratio, both the sandless concrete and normal concrete mixes had the same cement and water content. Furthermore, for each sandless concrete mixture, Class F fly ash was used to replace cement at 0, 10, 20, 30, 40 and 50%.

Table 1 : Mix proportions for normal and sandless concrete

Mixture Designation*	**Content, kg/m^3**					
	Cement	**Water**	**10-mm Coarse Agg.**	**20-mm Coarse Agg.**	**Sand**	***w/c***
M0.40-N	478	191	457	685	571	0.40
M0.40-S	478	191	683	1024	—	0.40
M0.45-N	444	200	457	685	571	0.45
M0.45-S	444	200	683	1024	—	0.45
M0.50-N	417	209	457	685	571	0.50
M0.50-S	417	209	685	1028	—	0.50
M0.55-N	393	216	457	686	571	0.55
M0.55-S	393	216	686	1028	—	0.55

* N : normal concrete; S : sandless concrete

2.2 Fresh Properties

No bleeding or segregation was observed in each concrete mix. The target slump was 50 mm, and a polycarboxylate-based superplasticizer was added for this purpose. The dosage of superplasticizer was limited to 2% of the total weight of cement and fly ash so as not to cause other problems such as delayed setting. The sandless concrete exhibited slump values of between 50 and 100 mm, except for the group with *w/c* = 0.40, as shown in Figure 2, which had slump values between 25 and 50 mm. According to ACI 211 (2002), the minimum slump requirement for structural construction is 25 mm; thus the sandless concrete satisfied this requirement. It is also noted that the replacement of cement by fly ash did not substantially improve the workability of concrete.

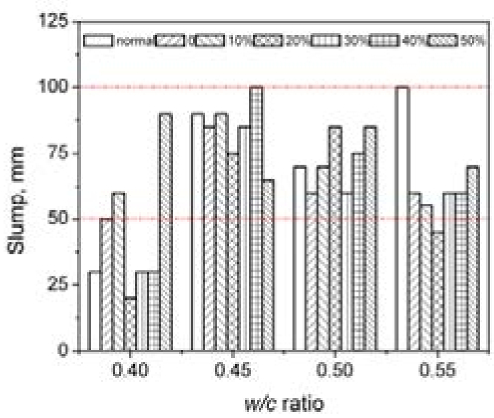


Figure 2: Slump of sandless concrete

2.3 Mechanical Properties

Figure 3 shows the mechanical properties of sandless concrete at 28 days, based on average of three samples per data point. It is seen from Figure 3(a) that sandless concrete without fly ash or with fly ash replacement ratio less than 20% exhibited similar compressive strength as normal concrete with the same *w/c* ratio. It was further found that at 90 days, the compressive strength for sandless concrete with *w/c* ratios of 0.40 and 0.45 was comparable to normal concrete, even with 50% fly ash replacement ratio, due to the late pozzolanic reaction of fly ash.

Figure 3(b) shows that the splitting tensile strength of sandless concrete without fly ash was comparable to normal concrete, and about the same regardless of the *w/c* ratio. The splitting tensile strength in fact increased with cement partially replaced by fly ash by up to about 30%, when *w/c* was below 0.5. For mixes with higher *w/c* ratios or with the fly ash replacement ratio exceeding 30%, the splitting tensile strength tended to decrease.

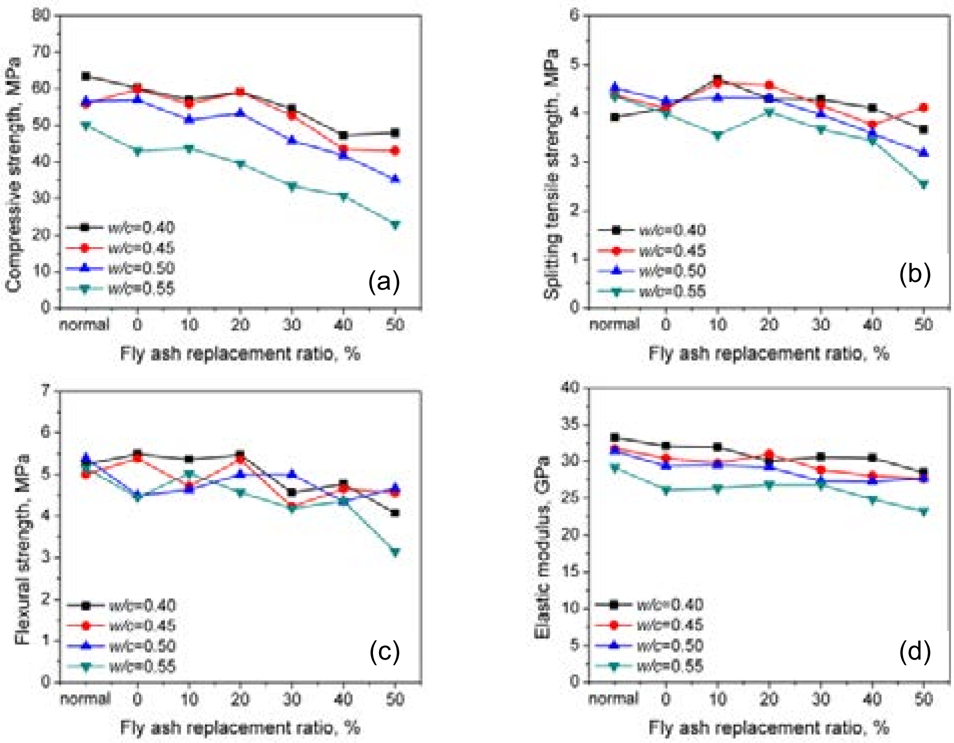


Figure 3: Mechanical properties of sandless concrete

The flexural strength refers to the modulus of rupture, obtained from prism tests. Similar to splitting tensile strength, Figure 3(c) shows that the flexural strength of sandless concrete was quite independent of the *w/c* ratio as long as it was below 0.50. The substitution of cement by fly ash did not lead to adverse effect if the replacement ratio was less than 30%. Also, at higher *w/c* ratios or with the fly ash replacement ratio exceeding 30%, the flexural strength tended to decrease.

The elastic modulus of sandless concrete, measured from cylinder tests and shown in Figure 3(d), was generally smaller than normal concrete due to the smaller stiffness of cement paste in the former compared to mortar paste in the latter. The modulus decreased with the *w/c* ratio, as is in normal concrete. For a given *w/c* ratio, the elastic modulus decreased with a higher fly ash replacement ratio, especially above 20 to 30%.

2.4 Drying Shrinkage

Figure 4 shows the drying shrinkage of sandless concrete. All the concrete mixes showed shrinkage less than 700 $\times 10^{-6}$ mm/mm after 180 days of drying. Also, the amount of drying shrinkage decreased with lower *w/c* ratio and increasing fly ash content. Compared to normal concrete, the drying shrinkage of sandless concrete without fly ash was higher at *w/c* = 0.55, slightly lower at *w/c* = 0.45 and 0.50, and lower at *w/c* = 040. With 50% sand replaced by fly ash, the reduction in drying shrinkage could be 27, 19, 24 and 40% for *w/c* ratios of 0.40, 0.45, 0.50, and 0.55, respectively.

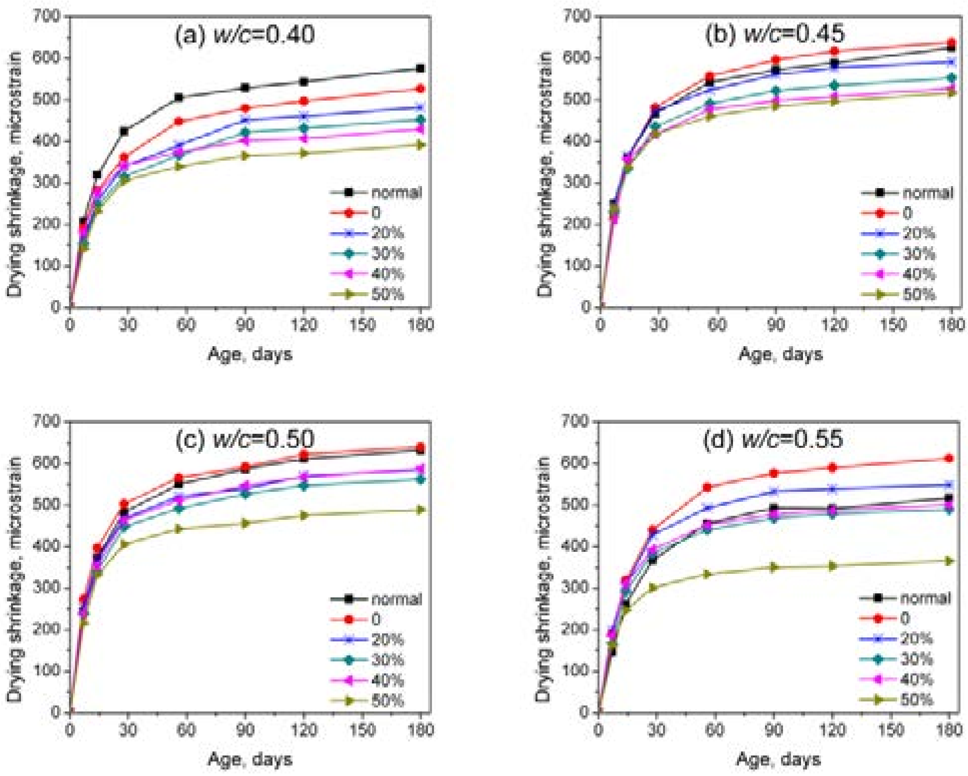


Figure 4: Drying shrinkage of sandless concrete

2.5 Chloride Resistance

Figure 5 shows the Rapid Chloride Penetration Test (RCPT) results of sandless concrete with *w/c* ratios between 0.4 and 0.55 inclusive at 180 days, as well as those of sandless concrete mix with *w/c* = 0.45 at 28 days. Sandless concrete showed lesser amount of charge passed, indicating a higher resistance to chloride ingress than normal concrete. This may be attributed to a reduction in the total surface area of aggregate particles and thus a smaller Interface Transition Zone (ITZ) that would have allowed the ingress of chloride ions (Mindess et al., 2003).

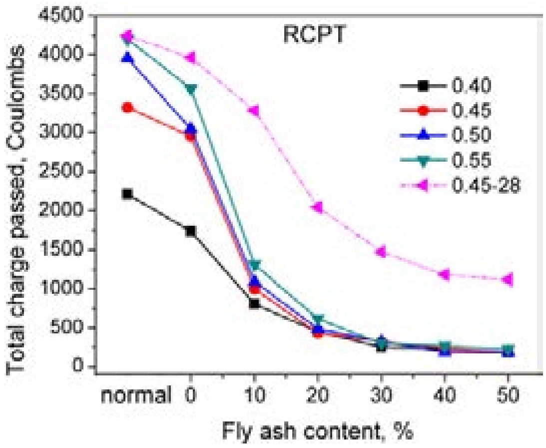


Figure 5: RCPT results for sandless concrete

The total charge passed was higher at 28 days than at 180 days. This was due to a higher degree of cement hydration which lowered the permeability of concrete. Also, the charge passed decreased with lower *w/c* ratios for sandless concrete, similar to normal concrete. It decreased with cement partially replaced by fly ash, and the effect was particularly significant for a fly ash replacement ratio of up to about 30%. This was because the microstructure of cement paste had been enhanced by pozzolanic reaction of fly ash, which resulted in reduced porosity and pore connectivity.

3. WASTE GLASS CONCRETE

In this study, recycled brown glass was used as sand replacement, with replacement ratio varying from 0 to 100%, in steps of 25%. Soda-lime glass bottles were first collected, washed and crushed into smaller particles, to satisfy the ASTM C 33 requirement for fine aggregates (see Figure 6). The crushed glass sand had more irregular shape, sharper edge, smoother surface and higher aspect ratio, compared to natural sand.

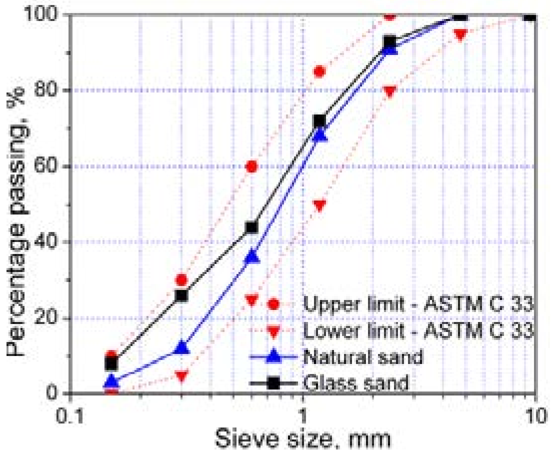


Figure 6: Grading of glass sand

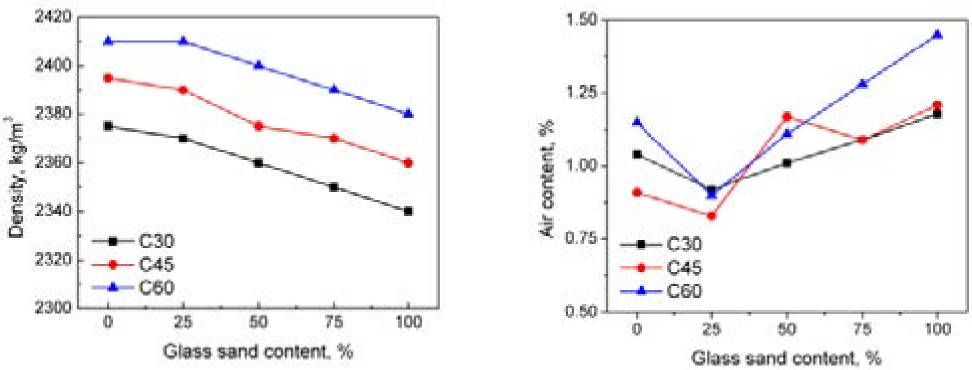
Three concrete grades with target characteristic cube compressive strengths of 30, 45 and 60 MPa and mix proportions listed in Table 2 were considered. The water and coarse aggregate content were kept constant at 185 and 1048 kg/m^3 respectively. To achieve a slump of 100 mm, superplasticizer was added at 1.3, 2.6 and 3.6 litres per cubic metre of concrete, for C30, C45 and C60 mixes, respectively.

Table 2: Mix proportion for glass concrete

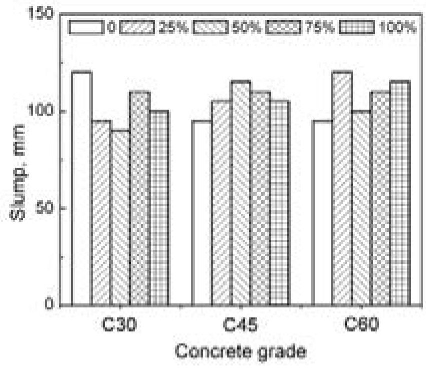
Concrete Grade	Mix proportions (kg/m^3)				*w/c*
	Water	Cement	20-mm Coarse Agg.	Sand	
C30	185	378	1048	741	0.49
C45	185	487	1048	649	0.38
C60	185	617	1048	540	0.32

3.1 Fresh Properties

The density, air content and slump of freshly mixed glass concrete are shown in Figure 7. Concretes with higher content of glass sand exhibited lower fresh density, due to the smaller specific gravity of glass compared to natural sand. The air content of glass concrete decreased initially with 25% glass sand, but thereafter increased consistently up to 100% glass sand. As regards workability, glass concrete showed slump values comparable to normal concrete without waste glass.



(a) Density (b) Air content



(c) Slump

Figure 7: Fresh properties of glass concrete

3.2 Mechanical Properties

Figure 8 shows the compressive strength, splitting tensile strength, flexural strength and static modulus at 28 days. It is noted that the compressive strength of concrete was not affected by the replacement of natural sand by glass sand even at 100%, especially for the lower grade concretes. For Grade C60 concrete, the use of glass sand led to slightly lower compressive strength. On the other hand, the tensile strength, especially flexural strength, was found to increase with higher glass sand content. This was due to the longer aspect ratio of glass sand and hence better interlocking action among aggregates. The static elastic modulus showed marginal increase with the use of glass sand.

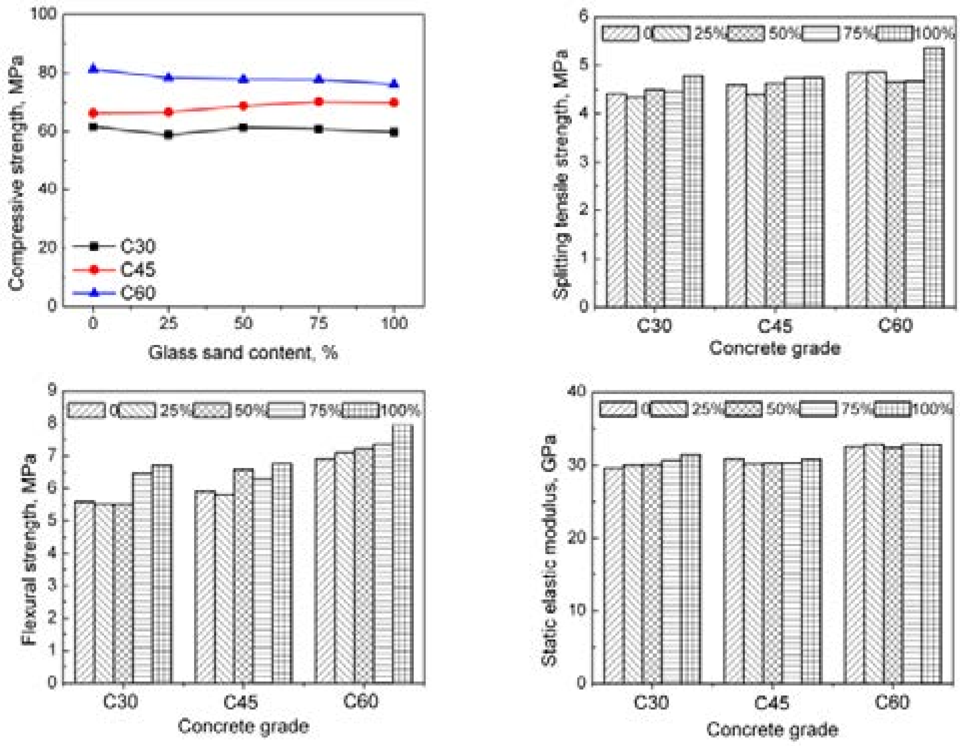


Figure 8: Mechanical properties of glass concrete

3.3 Alkali-Silica Reaction

Alkali-silica reaction (ASR) may be considered as the most deleterious mechanism for concrete containing glass sand. In this study, ASR expansions were measured according to ASTM C 1260 using mortar screened from freshly mixed glass concrete with a 4.75-mm sieve. Figures 9(a) to (c) shows the test results, up to 28 days for each concrete mix.

In general, glass sand showed less alkali-silica reactivity with cement than natural sand, regardless of the concrete grade. The ASR expansion continuously decreased with higher glass sand content. The increase in ASR expansion was also slower with higher glass sand content.

From Figure 9(d), each concrete mix showed ASR expansion less than 0.1% at 14 days, indicative of the innocuous nature of both the natural and glass sand used. Furthermore, the ASR expansion was found to be highest in the medium concrete grade C50. This pessimum effect occurred because while a lower *w/c* ratio in higher grade concrete led to more alkali ions for alkali-silica reaction, it also led to a higher tensile modulus of cement paste which resulted in lower ASR expansion. The former factor predominated in lower grade concrete, while the latter factor governed in higher grade concrete.

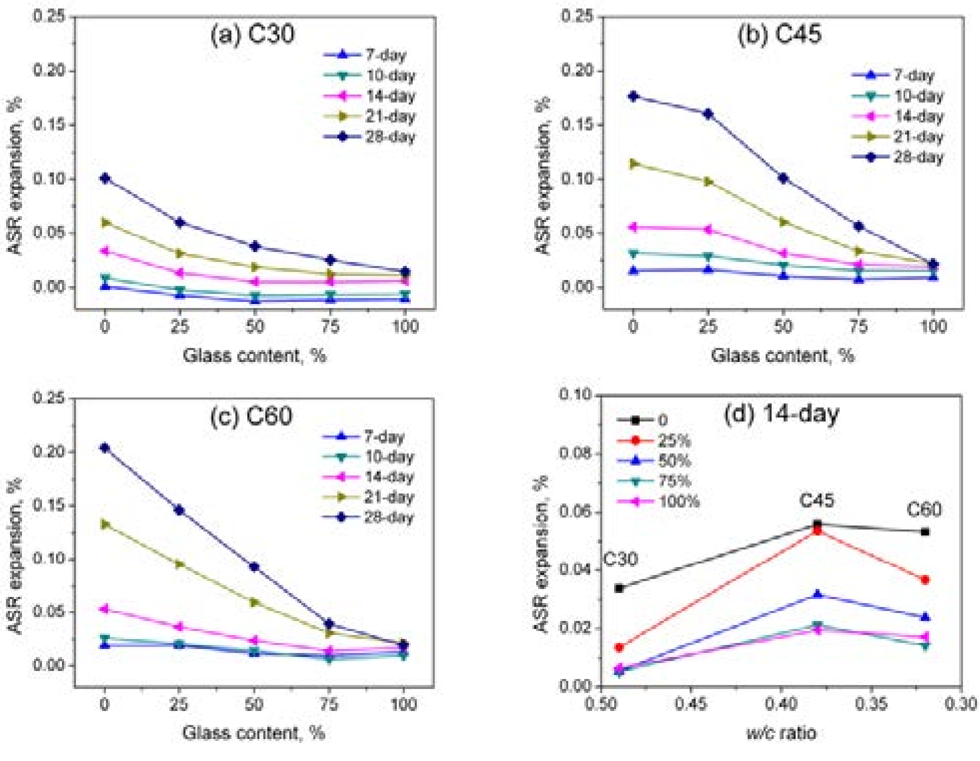


Figure 9: ASR expansion of glass concrete

3.4 Chloride Resistance

The resistance to chloride ingress was determined using the ASTM C 1202 Rapid Chloride Penetration Test (RCPT) method, and the NT BUILD 492 method (NORDTEST, 1999) for the determination of migration coefficient of chloride D_{nssm}. Figure 10 shows the test results at 28 days.

The resistance to chloride penetration was enhanced by the replacement of natural sand by glass sand. This could be attributed to the larger fraction of fines in glass sand (see Figure 6) which improved the micro-structure in the Interface Transition Zone (ITZ) between the paste matrix and glass particles (Mindess et al., 2003). Also, the lower porosity and irregular shape of glass particles compared to natural sand helped to reduce the ingress of chloride ions. Another possible reason could be due to the pozzolanic reaction of fine glass particles.

It was also noted that with higher grade concrete or with a lower *w/c* ratio, the total charge passed was substantially reduced due to reduced porosity of paste and increased impermeability of concrete, especially when the glass content was lower than 75%. The above observations were supported by the values of D_{nssm}, which also decreasd with lower *w/c* ratio and increasing glass content.

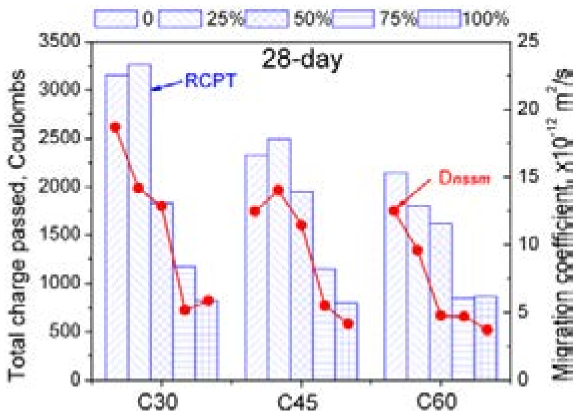


Figure 10: RCPT results of glass concrete at 28 days

4. CONCLUSIONS

In this study, sandless concrete was proportioned using dual coarse aggregates satisfying the ASTM C33 grading requirement for size 67 aggregates, while waste glass concrete was made using brown glass particles satisfying the grading requirement for fine aggregates. Test results indicated that both the sandless concrete and waste glass concrete possessed comparable fresh, mechanical and durability properties as normal concrete when the *w/c* ratio was lower than 0.5. The use of flyash as cement replacement further improved the properties when the replacement ratio was less than 30%. Such concretes were shown to be promising as alternative materials to conventional concrete, and should be explored further.

REFERENCES

ACI Committee 211, 2002. *Standard practice for selecting proportions for normal, heavyweight, and mass concrete* (ACI 211.1-91), American Concrete Institute, Farmington Hills, Michigan, USA.
ASTM, 1997, *Standard test method for bulk density ("unit weight") and voids in aggregate* (C 29), USA.
ASTM, 2003. *Standard specification for concrete aggregates* (C 33), USA.
ASTM, 2007. *Standard test method for determining the potential alkali-silica reactivity of aggregates (mortar-bar method*) (C 1260), USA
ASTM, 2005, *Standard test method for electrical indication of concrete's ability to resist chloride ion penetration* (C 1202), USA.
Mindess, S., Yong, J.F., and Darwin, D., 2003. *Concrete*. 2nd edition, Prentice Hall, New Jersey, USA.
NORDTEST, 1999, *Concrete, mortar and cement-based repair materials: chloride migration coefficient from non-steady-state migration experiments*, NT Build 492, Finland.

Potential strategies for promoting sustainable concrete practices in Thailand

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ABSTRACT

Sustainable development depends on a wide variety of factors but particularly on socio-economic conditions. Similarly, sustainable concrete practice may also vary, particularly between developed and developing countries – therefore, the relationship between sustainable concrete and such factors needs to be better understood. This research was conducted as a first step towards clarifying this relationship by interviewing stakeholders in the Thai concrete industry. Thailand represents a unique case for sustainable practice due to widespread adoption of fly ash concrete as the normal concrete material. Since the environmental impact of concrete is already reduced, the results of the interviews were used to not only explore the afore-mentioned relationship but also to consider potential strategies for promoting sustainability. It was found that, due to the low cost of labor, price serves as the most important criteria for concrete. This makes it difficult to test or adopt new technologies due to high cost competition. Most technology is diffused through the cement companies, which have the highest investment in R&D, although foreign consultants also provide such support. Finally, the lack of sustainability education makes it difficult to convince customers of additional value such as environmental impact reduction – thus education should form the base of promoting sustainable practice. Since environmental technologies cannot compete on cost, criteria for additional value are also necessary to concretely evaluate these characteristics.

Keywords: *Sustainability, concrete, Thailand, construction, environmental impact*

1. INTRODUCTION

More than 20 years after being initially defined in the Brundtland Report to the United Nations, sustainability remains difficult to implement due to the wide variety of perspectives on what, exactly, constitutes sustainability. This may be attributed to a critical aspect underlying the concept of sustainability: that it is a human vision with human values (Bell & Morse, 2008). What may be sustainable in one region of the world under a given set of social, economic, and environmental conditions may not be sustainable in a different region of the world under different conditions.

In a similar fashion, it is also difficult to establish a global strategy for sustainable concrete practice. General principles such as limiting CO_2 emissions, recycling and resource consumption reduction, and enhanced durability have been proposed (Mehta, 1999; Sakai, 2009), but how to practically achieve these goals depends heavily on available resources, construction industry culture and stakeholders, institutional systems, technology level, and more. These factors are affected by the regional or local socio-economic conditions, and in turn affect the potential for sustainable concrete practice and materials (Figure 1).

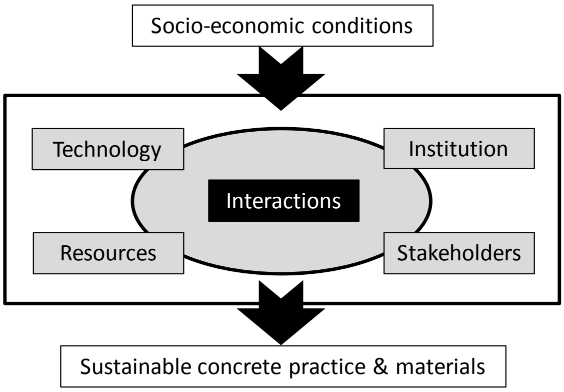

Figure 1: Conceptual framework for relating socio-economic conditions to sustainable concrete practice and materials

The Thai concrete industry was selected for this research because Thailand represents a unique case for sustainable concrete practice – not only due to its economic growth but also due to the widespread adoption of fly ash concrete as the standard material for concrete construction. Since the environmental impact – particularly CO_2 emissions – of concrete itself has already been reduced due to fly ash usage, other strategies for promoting sustainable concrete practice need to be considered. Through interviews with concrete industry members, this research investigated the relationship between socio-economic conditions and sustainable concrete practice and, from these results, proposed strategies for promoting sustainability considering Thailand's conditions.

2. RESEARCH METHODOLOGY

Conditions in the Thai concrete industry were investigated using semi-structured interviews, which followed a general outline but allowed for areas of interest to be explored in further detail (Punch, 2005). The interview contents were broken into four sections, as summarized in Table 1, with the goals of understanding the structure and relations among stakeholders, identifying different concepts for sustainability and sustainable concrete practice and materials in Thailand, and clarifying barriers to implementing those practices and materials.

Table 1: Outline of interview contents

Sec.	Theme	Description
1	Thai concrete industry conditions	Identify the stakeholders and their relationships, concrete evaluation criteria, characteristics unique to Thailand, and environmental impact
2	Knowledge of sustainability	Survey definitions, evaluation criteria, and level of awareness for sustainability in Thailand
3	Sustainable concrete practice and materials	Identify changes needed to achieve sustainability, evaluation criteria, and opportunities for Thailand to improve concrete sustainability
4	Barriers to sustainable concrete practice and materials	Clarify barriers and characteristics of Thailand which may overcome these barriers

The interviewees were not selected based upon any specific criteria, but were contacted through social and professional networking. Seven interviews were conducted in total, as shown in Figure 2.

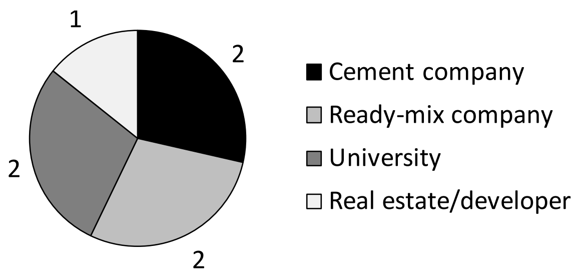

Figure 2: Distribution of interviewees

3. INTERVIEW RESULTS & DISCUSSION

3.1 Thai concrete industry conditions

The Thai concrete industry is composed of private owners, consultants, academics, government (as both public owner and material supplier), contractors, and ready-mix concrete (RMC), cement, and admixture companies. The two leading cement companies are the major stakeholders, and both have a large investment in research and development (R&D). Both companies also have their own RMC, and distribute cement both to their own producers as well as independent RMC plants. Fly ash, on the other hand, is produced by a public utility company from a power plant in northern Thailand. The RMC not only purchases chemical admixtures, but may also cooperate with admixture companies to develop customized admixtures based on specific requirements; the cement companies may also cooperate with admixture companies in a similar way. Investment in R&D in the cement/RMC companies focuses on cement technology and the development of new materials.

The customer of the RMC is either the contractor (generally for public projects) or the project owner (more typical of private sector projects). Local contractors have a lower level of technology compared to the cement companies and generally only work on smaller projects; overseas contractors, on the other hand, have a higher level of technology and work on major projects, either alone or as a venture with local companies. On the owner side, for public works there is limited investment in R&D in only a few government departments – the owner generally relies on a consultant who may then cooperate with a university, joint venture, foreign investment or other entity. Outside of the private sector, leading universities have a large investment in R&D and work to solve industry problems and support industry stakeholders through associations and collaborative works.

Transfer of new technologies generally occurs through the cement/RMC companies or from the leading universities. This is done by understanding customer needs, current technologies, market opportunities, lessons learned from practice, and so on. However, in Thailand the most critical aspect of any new technology is cost. Most concrete-making materials – cement, fly ash, and aggregates – are locally available and thus their cost is very low. But more so than materials, the cost of labor in Thailand is extremely cheap, to the point where most technologies simply cost more than the labor they are intended to replace or supplement and, thus, it's cheaper to use people rather than machines. One example is fiber-reinforced concrete (FRC). FRC replaces reinforcing steel bars with fibers, which reduces labor costs due to reduced steel content; however, the cost of the fibers is much higher than the labor cost so it's not economical. Another example is self-compacting concrete, which saves labor costs related to casting, but again the increased cost of materials is more than the labor costs. Therefore, the industry operates at a lower level of technology compared to developed countries such as Japan, where labor costs are significantly higher.

Due to the low cost of labor and local availability of materials, competition in the concrete industry is intensely focused on cost, and the majority of government projects still rely on initial cost only. Therefore, introduction of new materials or construction processes is difficult if they don't reduce cost or construction time. There is little consideration of additional value (such as durability, life cycle cost, etc.), making it hard for "value-added products" to compete in the marketplace. Some companies have tried to move towards additional value in the form of service, such as guarantees and customer support, but these are typically offered "free of charge" to maintain price-competitiveness of the product or service being sold while trying to gain an additional advantage.

A good example of cost minimization in concrete materials is the wide-spread use of fly ash in concrete in Thailand, which is mostly due to its lower cost relative to cement. Since cement is the most expensive material component in concrete, large cost savings can be realized if this volume is reduced. The environmental and material benefits of fly ash are therefore secondary to the cost savings, and were fly ash to cost more than cement it would become a premium product. Even though fly ash is widely accepted, however, its usage is still restricted by prescriptive design codes which specify a minimum cement content in concrete.

Finally, for environmental impact, waste generation and disposal is an issue which needs addressing. It's cheaper to throw away demolition waste and left-over concrete from construction sites and RMC plants than it is to recycle it. Furthermore, the cost of recycling technology is high, and resources are still abundant, so there is little motivation to consider this problem. Another issue is the generation of dust, noise, and other social and environmental hazards around cement and RMC plants and construction sites. These stakeholders are concerned that, if they don't maintain good relations with their surrounding communities, it may lead to protests or other difficulties which could negatively affect the stakeholders' productivity and image.

3.2 Knowledge of sustainability

When asked to define sustainability in their own words, the interviewees gave a variety of responses. These included the minimization of resource and energy consumption, the "three pillars" (economy, environment, society), and corporate governance. However, it was acknowledged by some interviewees that sustainability can have different meanings, making it difficult to clearly define. The consumption of natural resources, CO_2 emissions, and waste production were identified as general means of evaluating sustainability.

For Thailand in particular, it was said that generally few people are aware of sustainability as an important issue. People just want a nice living space and are not concerned about green construction. Cost is the primary consideration, and it's hard to weigh sustainability against cost because people do not consider social or environmental factors. On the business side, however, it's important for companies to consider the social impact of their activities in particular, in order to maintain good relations with the local communities. Another important aspect of sustainability for Thailand is the lack of domestic energy production. Conservation of energy is important because of the difficulty in constructing large energy facilities in Thailand. Finally, instability and corruption in the government were also identified by the interviewees as important issues which need to be overcome for sustainability, because when the government changes it often discontinues the policies of the previous administration in order to forge a new identity, thus making it difficult to have confidence in new policies.

3.3 Sustainable concrete practice and materials

To move towards sustainable concrete practice and materials, the interviewees identified several different areas which need to be considered for Thailand. These are summarized in Figure 3 and are divided into three groups: concrete and sustainability evaluation criteria and general actions.

On the concrete aspect, the interviewees suggested that durability needs greater consideration in order to use concrete structures longer. This is best evaluated by utilizing life cycle cost (LCC) as an evaluation criterion, which provides a quantifiable means for understanding and comparing; however, a Thai-specific standard, rather than international standards adapted for Thailand's uses, is necessary to properly capture the conditions experienced in Thailand.

For the sustainability aspects, CO_2 emissions was mentioned as a useful evaluation criterion for environmental impact because it can be easily quantified, such as mass of CO_2 per cubic meter of concrete. Although the cement content in concrete is already reduced due to usage of fly ash, the cement industry needs to reduce its environmental impact further, particularly looking at the CO_2 emissions and resource and energy consumption in cement production. This is one area where the Thai industry may be able to implement strong action because the cement companies are the strongest stakeholders; in addition, they can control the production of concrete within their own companies and thus can directly reduce environmental impact from the beginning of the material production process. However, performance-based design and standards need to be implemented to allow greater freedom in utilizing new materials or technologies.

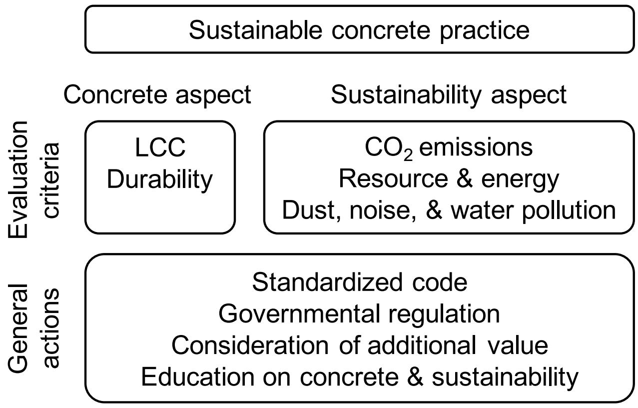

Figure 3: Evaluation criteria and actions for moving towards sustainable concrete practice and materials

Not only should the environmental impact of the materials be reduced, but the impact of the manufacturing and production plants themselves should also be reduced. This includes dust, noise, and water pollution, all of which can have detrimental effects on the surrounding community. Governmental regulation for establishing air-borne particulate matter standards, noise limits, and so forth would help the cement and RMC plants and construction sites better manage their local impact and establish benchmarks for improvement.

To move towards these evaluation criteria, the first important action is the establishment of codes and guidelines to provide the industry with a standardized method for evaluating and design considering durability, life cycle cost, and environmental impact. As mentioned before, such codes and guidelines need to be developed considering the Thai industry's conditions. Governmental regulation was also already mentioned as necessary, for guiding not only the environmental impact reduction but also durability and long-term maintenance of concrete structures. These actions will require increased consideration of the additional value of concrete materials, such as durability and environmental impact, in order to shift the focus away from pure cost evaluation. However, the most fundamental action necessary is education at all levels of the industry, as well as education of non-industry members who interact with the industry, such as owners, government official and bureaucrats, local communities, and more. First, this education is necessary to reduce the emphasis on cost by providing information about the additional benefits concrete can have. Second, the education is necessary to raise the ability of those working in rural areas, whose skill levels and knowledge of concrete materials and construction are much lower than that of workers in Bangkok. Third, the education should change people's perception of concrete, from that of a simple construction material to that of a complicated, multi-component material which can provide a given service level in any number of ways and combinations of component materials. Finally, people are not aware of sustainability as an issue and thus need to be instructed about the principles of sustainability and how it applies to construction and concrete.

3.4 Barriers to sustainable concrete practice and materials

The barriers to sustainable concrete practice and materials are given in Table 2. Fourteen barriers were identified in total, and these are separated into five general categories: institutional, socio-political, economic, technological, and knowledge.

Table 2: Barriers to sustainable concrete practice and materials by category

Institutional
• Lack of performance-based design for concrete materials and structures • Lack of standardized codes for durability and life cycle assessment • Lack of institutional laws and regulations from the government • Gap between research activities and practical implementation • Focus on initial cost only in construction contract bidding
Socio-political
• No motivation to specify or utilize sustainable materials and technologies • Political instability leads to inconsistent public policies
Economic
• Investment in research and development doesn't increase market share • No market for sustainable or environmentally-friendly products • Cost of new technologies is higher than cost of labor or materials
Technological
• Low level of technology
Knowledge
• Lack of knowledge on sustainability and environmental impact • Lack of education among concrete industry stakeholders • Lack of knowledge on additional value (durability, environmental impact, etc.)

Institutional barriers number the largest and include the need for performance-based design and standardized codes for durability and life cycle assessment, as well as action on the part of the government such as laws and regulations to provide incentive and guidelines for the industry to operate within. Difficulty in converting research results into practical and implementable technologies and methodologies was also a concern. However, the most emphasis was placed on the focus on initial cost in construction. This supports previous statements regarding the importance of cost over other criteria and the high cost competition in the Thai concrete industry.

Socio-political barriers include the lack of motivation to specify sustainable materials and technologies in concrete-related areas and the lack of consistent public policies due to political instability. These are directly related to the institutional barriers discussed above; laws and regulations would provide a motivating factor for specifying and utilizing sustainable materials and technologies, but it's difficult to implement such policies due to the changing political situation. The three economic barriers cover the difficult in investing in R&D when competing on cost, the lack of a market for sustainable or environmentally-friendly products, and the cost of new technologies relative to the cost of labor and materials. Since competition is primarily based on cost, there is no guarantee that investment in R&D will provide economic returns. Furthermore, since the cost of labor and materials is already so low, even if new technologies are developed they may still be difficult to implement due to their higher cost.

The technological barrier focuses entirely on the low level of technology in the Thai industry, which is understandable in the context of the previous discussion on the costs of higher-level technology. Finally, the knowledge barriers are focused on the lack of knowledge about sustainability, environmental impact, and the additional value of concrete materials, as well as a lack of higher education among some members of the concrete industry, particularly in rural areas.

4. POTENTIAL PROMOTION STRATEGIES

Based upon the interview results, the low cost of concrete-making materials and labor in concrete construction in Thailand is a large obstacle for moving towards more sustainable practices and materials, making it difficult to introduce additional value and experiment with new technologies in practice. This low cost can be seen as a function of the low cost of labor and the local availability of concrete-making materials. Since these factors are fundamental aspects of Thailand's socio-economic status and location, means for promoting sustainable concrete practices and materials need to be considered which can complement these conditions.

The starting point should be education, as people are unaware of both the complexity of concrete and the potential for concrete as a sustainable construction material. Raising awareness is a necessary step towards developing a market for environmentally-friendly and sustainable technologies. In addition, by better-educating people about the possibilities of concrete, such as the variety of alternative cementitious materials, durability against environmental deterioration, usage of recycled materials, and so on, it may open possibilities for new uses and new technologies, which will in turn help raise the level of technology. Education of the government and owners will help move towards regulation and standardization based upon Thai needs and conditions. These may be necessary to spur the industry into action and push technology forward.

As discussed with the interviewees, one of Thailand's strengths lies in its academic and professional institutions. There is already some push towards consideration of sustainability in these (for example, the Thai Concrete Association has a subcommittee on energy and environmental conservation), and these institutions can help to overcome many of the barriers discussed above, and may even work in tandem with the education suggested previously. For example, if there is no demand for a standard such as durability or CO_2 emissions, the institutions may develop or provide such a framework based upon their professional knowledge and make the framework available to interested parties. Then, if interest or demand grows, such a framework could serve as a base for a larger, more-industry wide standard – or could be modified depending on the needs of the industry. In this way, as found in the interviews, the academic and professional institutions in Thailand may serve to provide a foundation for future industry growth to build upon.

5. CONCLUSIONS

It is necessary to consider differences in socio-economic conditions as part of the movement towards sustainability in the concrete industry, as concrete construction depends on so many conditions – such as resource availability, technology level, institutional framework, industry culture, and more – which vary widely. In the case of Thailand, it was found that local availability of resources and low labor costs have led to an industry which focuses intensely on cost competition, making it difficult to introduce new technologies which don't reduce cost or to evaluation materials, technologies, or services on criteria other than cost. Education could help raise awareness of industry stakeholders and thus open new markets for sustainable technologies, but such education needs to take into account the needs of the Thai industry and Thailand. Academic and professional institutions can also serve a powerful role by preparing the way for future trends and setting a basic framework in place which could be later taken up by the wider industry, should demand and interest increase. However, the cement and RMC companies will probably play the largest part, as they are both the strongest stakeholders, with the largest investment in R&D, and can also help reduce environmental impact from the initial stages of production.

REFERENCES

Bell, S. and Morse, S., 2008. *Sustainability indicators: measuring the immeasurable?*. Earthscan, London.
Mehta, P.K., 1999. Concrete technology for sustainable development. *Concrete International* 21(11), 47-53.
Punch, K.F., 2005. *Introduction to Social Research*. SAGE Publications, London.
Sakai, K., 2009. Towards environmental revolution in concrete technologies. *Proc. 11th Annual International fib Symposium, Concrete: 21st Century Superhero*. fib, Lausanne.

Feasibility study of new repair methods for underground civil infrastructures based on crack self-healing technologies

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ABSTRACT

In this study, new repair methods based on crack self-healing technologies were suggested in order to prevent water leakage in underground civil infrastructure such as tunnels. First, shotcrete with self-healing capability was examined in comparison with normal shotcrete without self-healing capability. The results of water pass test after cracking show that cracked shotcrete concrete mixtures incorporating self-healing agents exhibit much higher self-healing behavior than in cracked normal shotcrete concrete mixtures. For new repair materials with self-healing capability based on crack injection method, various repair materials were observed. Cracks with an initial width of 0.2 mm in the case of some mix proportions were almost healed after water passing tests. Finally, the effects of various hydration phases on the self-healing mechanism were analyzed using TG-DTA, Digital Microscopy and SEM(EDS). From these concepts, some particular mix-proportions for new repair method with self-healing capability were suggested.

Keywords: *crack self-healing, repair materials, shotcrete, crack injection method*

1. INTRODUCTION

Crack in concrete is one of the biggest problems in terms of durability of infrastructures. Maintenance and repair of cracked concrete are also very important for civil engineering fields. In such a background, there is the much interest to the practical use of the crack self-healing concrete that can be greatly reduced the maintenance cost. Water proofing sheets are usually provided between concrete lining and surrounding ground for tunnel and large-scale underground structure as the water leakage prevention method. However, it is extremely difficult to achieve a complete waterproof because water easily penetrates through defect parts. Therefore, if the function to recover the water

leakage prevention effect can be provided to concrete, it will be ideal for engineer and owner. (T.H. Ahn, 2008)(T.H. Ahn et. al, 2009)
Recently, several researchers suggested new repair methods based on crack self-healing technologies for underground civil infrastructures as tunnels.
This study aims to develop the shotcrete incorporating self-healing agents for the underground civil infrastructures without water-leakage as shown in Figure 1(a). Moreover, new repair method was also studied as shown in Figure 1(b) where the hole was prepared for repair work of cracks with suitable intervals under water leakage, and it was filled with the inorganic repair materials incorporating self-healing agents. This study was performed to investigate the self-healing capability of inorganic repair materials to cracks under water leakage conditions.

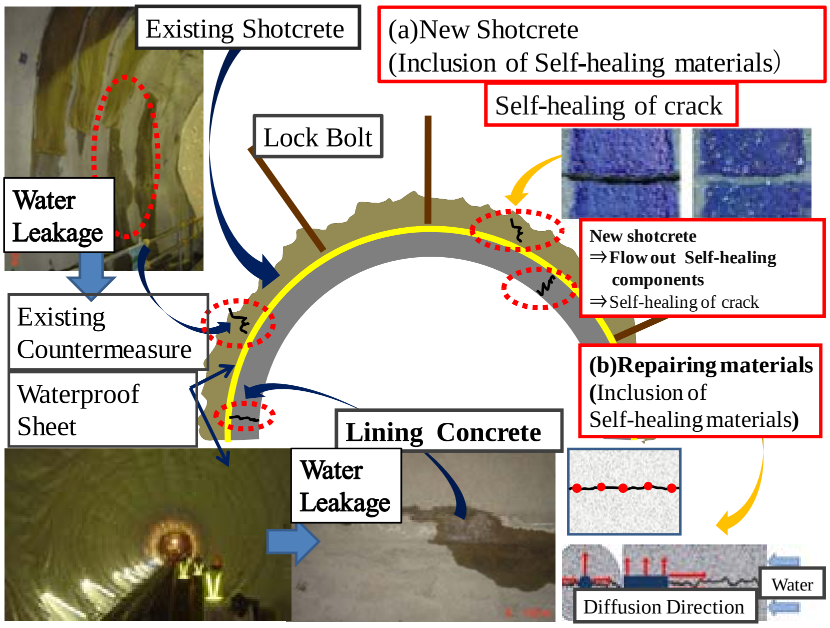


Figure 1:Application concept of self-healing technologies for underground civil infrastructures as tunnels

2. EXPERIMENTAL PROGRAM

2.1 Raw materials[1)]

In this research, various mineral admixtures such as expansive agent, geo-materials, and chemical agents were used in order to fabricate the self-healing admixture based on previous research.

2.2 Estimation of waterproofing effects based on the new shotcrete incorporating self-healing agents

When the cracks occur in the shotcrete incorporating self-healing agent, it is expected that the self-healing agent begin to diffuse into underground water which passes the crack. When this underground water passes the crack of the lining concrete, the self-healing hydrates form in the crack, and there is a possibility that the crack becomes blocked. From the above-mentioned scenario, the waterproof effects of the shotcrete incorporating self-healing agents were investigated.

2.2.1 Specimens and water pass test

12 specimens (ϕ 100 × 300mm) were prepared, Table 1 and 2 show the mix proportions of shotcrete and tunnel lining concrete in this research.

Table 1: Mix-proportion of artificial shotcrete

	Water binder ratio W/C(%)	Water W	Cement C	Self-healing agent SH	Sand S	Gravel G	Super plasticizer SP	Quick setting admixture
OPC	59.2	213	360	0	1074	692	0	18
SH10%			324	36			5	
SH30%			252	108			7	
SH50%			180	180			16	
SH15%(1)			306	54			0	
SH15%(2)			306	54			7	

Table 2: Mix-proportion of tunnel lining concrete

	Unit content(kg/m^3)			
W/C(%)	Water W	Cement C	Sand S	Gravel G
47.3	175	370	809	920

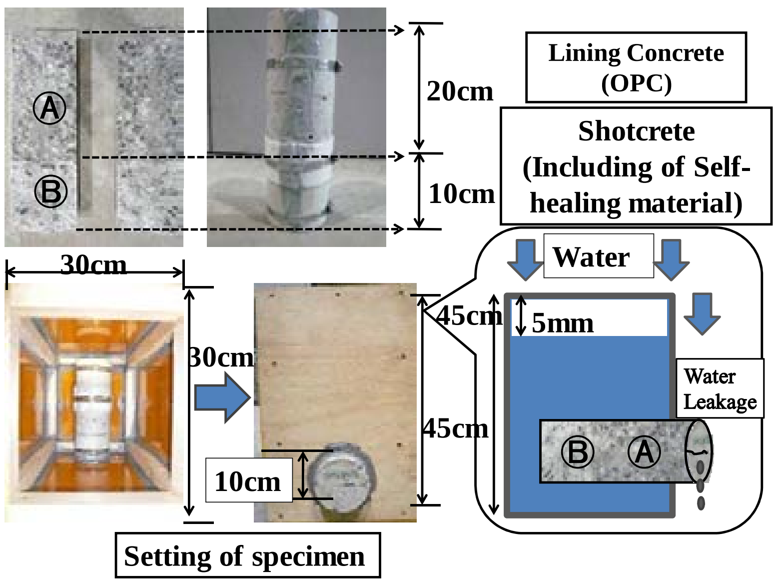


Figure 3: Specimens and water pass test for the shotcrete

First, artificial shotcrete incorporating self-healing agents was cast with around 10 cm thickness. And then, 20cm thickness of ordinary concrete was cast as the tunnel lining concrete after one day. The accelerating agent with aluminate salts was also used in the artificial shotcrete. Particularly, SH15%(1) and SH15%(2) have high amounts of expansive agent and swelling materials respectively compared to other specimens. The specimens were demolded and cured for 28 days. After curing, all specimens were splitted by compression testing machine and then crack width was controlled around 0.2mm by Teflon sheets. Finally, the specimens were re-bonded with the hose clamp, and then the circumference side of the specimen was sealed and also the inside container is closed with epoxy resin. The set-up for water pass test was prepared as shown in Figure 3 The water flow through a crack was measured after filling water in the container. The elapsed time are recorded when the surface of the water decreased 5mm. This measurement was conducted on the 0, 1, 3, 7 and 14 days.

2.3 Estimation of water leakage proofing effect by plugged inorganic repair materials incorporating self-healing agents

In the second stage, waterproof effects of plugged repair materials incorporating self-healing agents were investigated based on the concept as shown in Figure 1(b).

Table 3: Mix-proportions of repairing materials

Specimen	Water binder ratio	Unit content(g)		
		Ordinary poltrand cement	Self-healing agent	Repairing material types
	W/B(%)	OPC	SH	
A	0	0	0	None
C	30	60	140	Swelling type
D		140	60	Complex type

※B: Commercial products

The length of the specimens was fixed around 30cm by referring that of general lining concrete in tunnels. Moreover, two types of specimens (ϕ 100mm and ϕ 150mm) were prepared in order to estimate the diffusion area of repair materials. Small hole (ϕ 2cm X 10cm) from crack surface was prepared and then the repair material is plugged. Table 3 shows the mix proportions of repair materials in this research. And then, waterproof effects of repair materials were estimated under water leakage condition as shown in Figure 4.

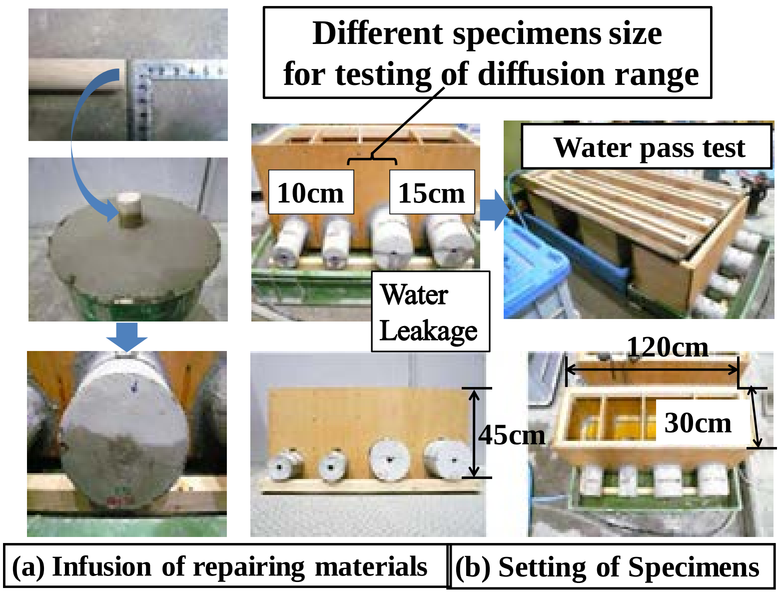


Figure 4: Specimens and water pass test for repair materials

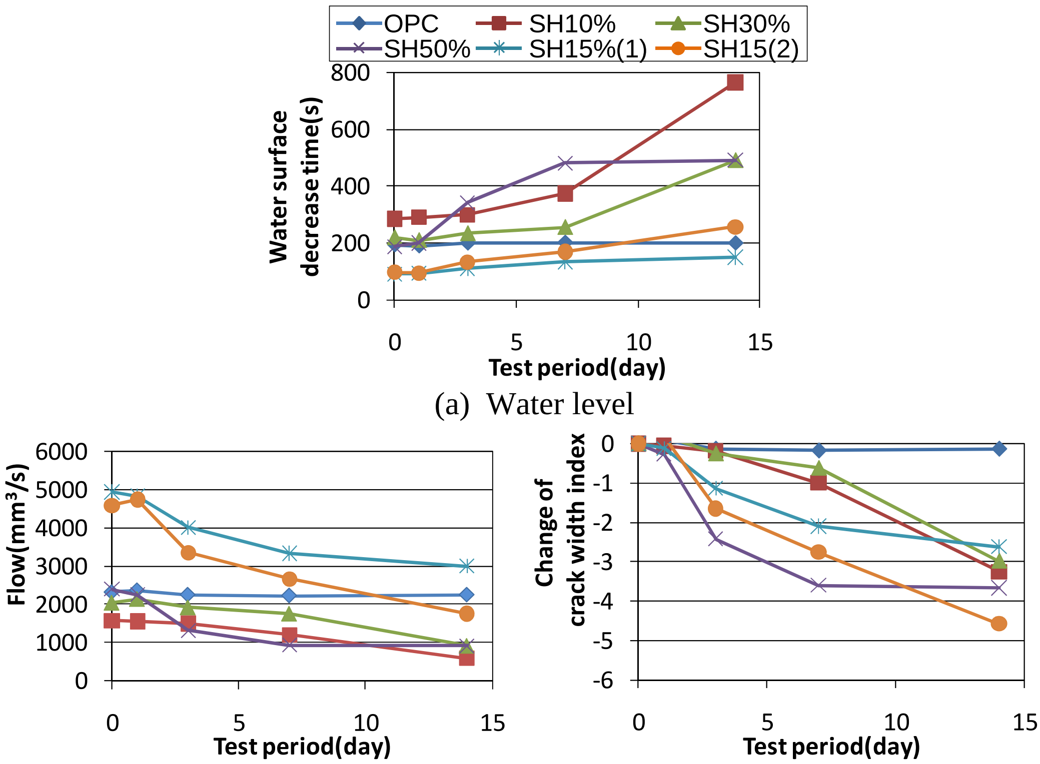
2.4 Observation and analysis of the specimens after water pass test

All specimens after water pass test were observed in order to clarify the self-healing capability. Microscopy and SEM with EDS-detector were carried out to investigate the morphology, shape, and size of re-hydration products and to clarify the mass transport process for recrystallization. Moreover, the carbonation of re-hydration products was measured using TG-DTA.

3. RESULTS AND DISCUSSION

3.1 Waterproof effects of shotcrete incorporating self-healing agents

Figure 5 shows the result of water pass test using the self-healing concrete in the shotcrete. Figure 5(a) shows water surface decrease time, Figure 5(b) shows water flow per unit time and Figure 5(c) shows the change of crack width index. In Figure 5(a) and (b), the negligible differences were seen at the initial values, since the introduced crack widths and surface shapes are not uniform though the width of the crack was controlled to about 0.2mm. Therefore, two dimension Poiseuille Equation (1) that was able to consider the difference of ruggedness in the crack width and crack shape in each specimen was used and examined. The crack width index is evaluated by the cube root of flowing quantity q calculated from Equation (2) as shown in Equation (3).



(a) Water level

(b) Water flow (c) Change of crack width index

Figure 5: Waterproof effects of shotcrete incorporating self-healing agents

$$q = C \cdot \frac{b \cdot \Delta P}{12 \cdot \mu \cdot L} w^3 \quad (1), \qquad q = \frac{V}{t} \quad (2)$$

Where,
q:flow(mm³/s), C: Coefficient in which ruggedness of crack is considered, b:Length of crack (mm), ⊿P:Water head difference (N/mm²), µ:Viscous modulus of water , L: Length of waterway (mm), w:Crack width (mm), V:Decrease volume of 5mm water surface (mm³), t:Decrease time of 5mm water surface (s)

$$q = C \cdot \frac{b \cdot \Delta P}{12 \cdot \mu \cdot L} w^3 \Rightarrow \begin{array}{l} w' = \sqrt[3]{q} \\ W = w' - w_0' = \sqrt[3]{q} - \sqrt[3]{q_0} \end{array} \quad (3)$$

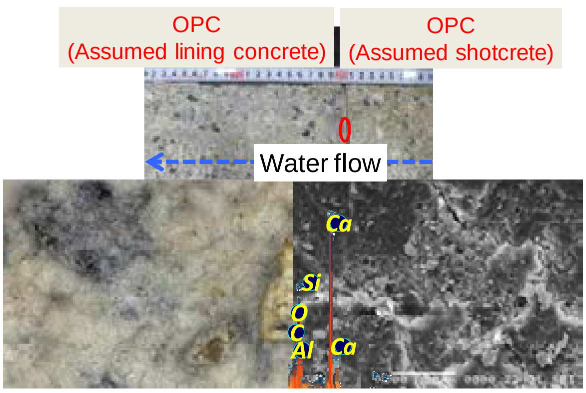
Assumption
assumed to be constant

Where,
w':Crack width index , q:flow (mm³/s), W: variation of crack width index (mm), w'_0:Initial crack width index (mm), $\sqrt[3]{q_0}$:Initial flow (mm³/s)

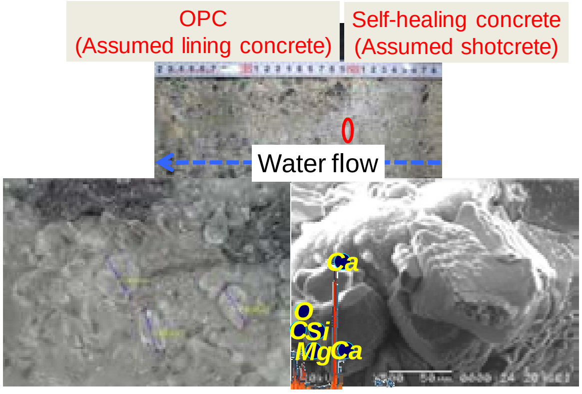
This study aims to estimate the crack self-healing capability according to the change of crack width index. Figure 5(c) shows that OPC without the self-healing agents didn't change the crack width index. On the other hand, SH10%, 30% crack width index decrease gradually until the 14th day. As for the final value case, SH10% is better than SH30%, and SH10% waterproof effect became significant. A great waterproof effect is demonstrated in ease SH50% on 1st day. However, it is almost constant after the seventh day. The result of SH15%(2) has improved most and it is thought that the swelling agents became more runny because initial flow quantity was large as shown in Figure 5(b). Consequently, it can be confirmed that the waterproof effect is promoted with increase of the self-healing agents. However, if the increased amount is too much, the waterproof effect may be not effective. This fact may indicate that chemical stability of products decreases if dosage of self-healing agent exceeds a certain value.

3.2 Diffusion effect of self-healing agents incorporated in shotcrete

The specimens were divided after the water pass test in order to investigate effects of shotcrete with the self-healing capability. And then, the crack section of the specimens were observed and analyzed.



(a) Normal shotcrete (OPC)

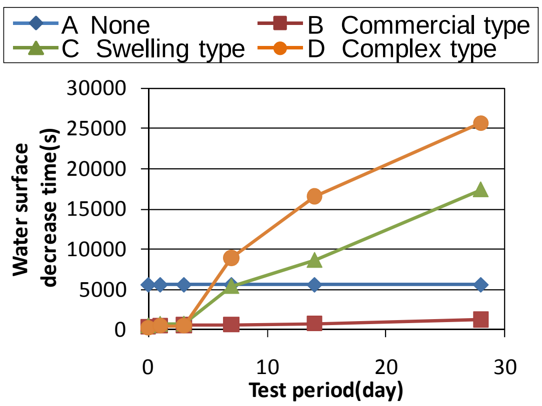


(b) Shotcrete incorporating self-healing agents (SH50%)
Figure 6: Re-crystallization between cracks under water leakage

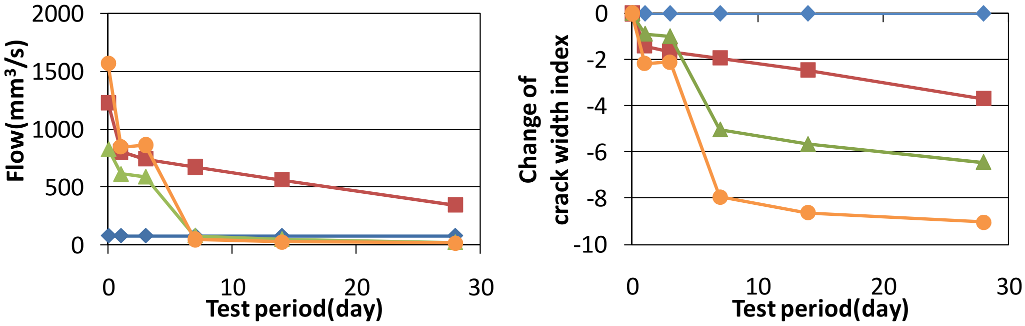
The SH50% specimen showed best waterproof effect at the early stage compared to OPC and thus, the crack surface of SH50% specimen was observed and analysed in comparison with OPC one as shown in Figure 6. It was found that re-hydration products such as $CaCO_3$, $MgCO_3$, and magnesium silicate phases were formed between cracks due to accelerated diffusion in SH50% specimen.
Moreover, crystal size of re-hydration products was also bigger than that of OPC. This indicates that self-healing agents significantly affect the formation of re-hydration products and its size may become bigger. It is suggested that self-healing agents may be worthy to be adopted for the design of new shotcrete.

3.3 Waterproof effects of inorganic repair materials incorporating self-healing agents

The results of the ϕ150mm specimen are shown in Figure 7. Figure 7(a) shows the result of the water surface decrease time and Figure 7(b) shows the result of flow evaluated. Moreover, the crack width index was evaluated by Equation (3) as the cube root of water flow q. Further, to relatively evaluate the change in the crack width by the self-healing agents, the change of the crack width index from the initial value is shown in Figure 7(c). In a case of ϕ100mm specimens it was found that B showed the best performance for waterproof effect. As shown in Figure 7, however, C and D appeared to be most effective in waterproof effect in case of ϕ150mm specimens. A lot of swelling materials are contained in specimen C and D.



(a) Water level



(b) Water flow (c) Change of crack width index

Figure 7: Waterproof effects of inorganic repair materials incorporating self-healing agents(ϕ 150mm)

3.4 Diffusion effect of self-healing agents incorporated inorganic repair materials

Photo 1 shows surface of the specimens after water pass test. The secondary phases were formed on the upper side of the surface in case of specimen B. It did not depend on the specimen size. On the other hand, it was also found that specimen D had both clean surface and good waterproof effect under water leakage condition. Therefore, the fracture surface of specimen D was observed in detail after water pass test. First, SEM-EDS and TG-DTA analysis were conducted for specimen D with ϕ 100mm and the diffusion section which is the area near plugged repairing material at crack surface of repair materials was investigated as shown in Photo 2 and Figure 8.

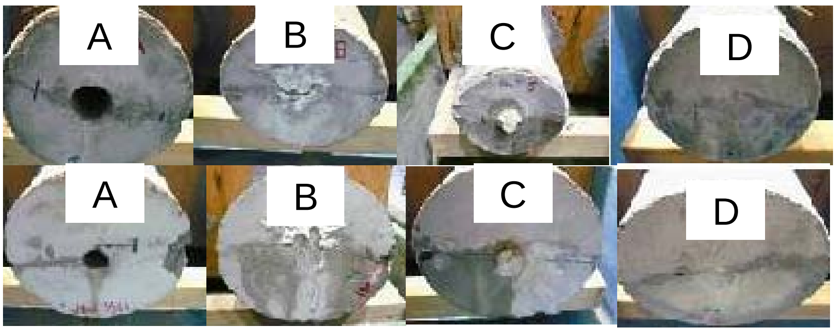
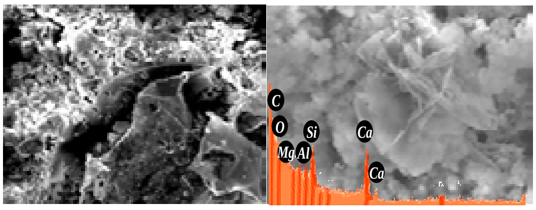


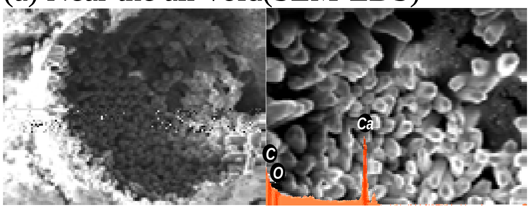
Photo 1: Specimens after water test(Above: ϕ 100mm, Below: ϕ 150mm)

It was found that some air void is occupied by crystals as shown in Photo 2(a) left picture. It was confirmed by SEM-EDS result that alumina-silicate-hydrates phases were formed there as shown in Photo 2(a) right picture. Moreover, the crystal formation of $Ca(OH)_2$ seems to be a reaction from the unhydrated part of cement. In addition, it was found a lot of $CaCO_3$ also formed on the surface of matrix around air void as shown in Photo 2(b). And then, it is confirmed that peak of $CaCO_3$ exists at about 750℃ in the result of TG-DTA as shown in Figure 8. Furthermore, It was found by DTA curve at around 100℃ that the ettringite was also formed. Therefore, the re-hydration products such as aluminate-silicate hydrates, $CaCO_3$ and ettringite were formed at crack surface near plugged repairing material in specimen D. Furthermore, the results of analyses by the

SEM-EDS and TG-DTA for the product formed on the end bottom of the same specimen are shown in Photo 3 and Figure 9. From these results, it was found that the $CaCO_3$ is mainly formed in the bottom end surface. It is unique that the crystal shape of $CaCO_3$ was oval type. In Figure 10 the detailed observation at various positions on the crack surface of the same specimen along the path of the water flow is shown. The observed Parts A, B, C, and D are located at 0cm, 10cm, 15cm, and 20cm from the water inflow point as shown in Figure 10. At Part A, it is found that a lot of tiny holes are seen and it is supposed that a part of pastes or tiny aggregates were flowed out. A lot of defective parts on the surface were also seen at Part B, too. On the other hand, the needle shape crystals are generated in Part C and D. Because Part C is far away from the plugged repairing material, the generation of the needle crystal is sparse compared to Part D. In part D some bright products are also seen. The tiny particles released near the inflow are supposed to be carried down by the influence of advection and they might be trapped at the narrow space between crack surfaces. Subsequently they might play roll as formation sites and the crack blockage by clogging might happen.



(a) Near the air void(SEM-EDS)



(b) Inside the air void(SEM-EDS)
Photo 2:Cross section near the crack(φ100mm)

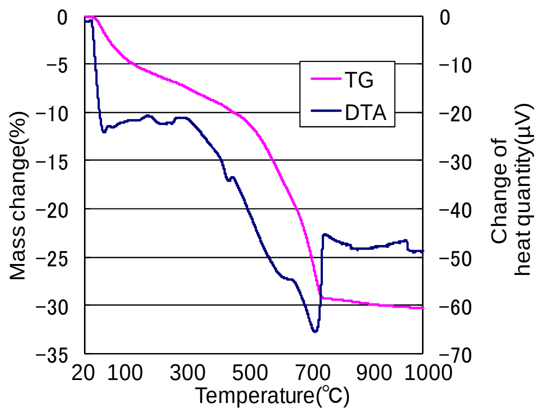


Figure 8:TG-DTA(φ100mm, Specimen D diffusion section)

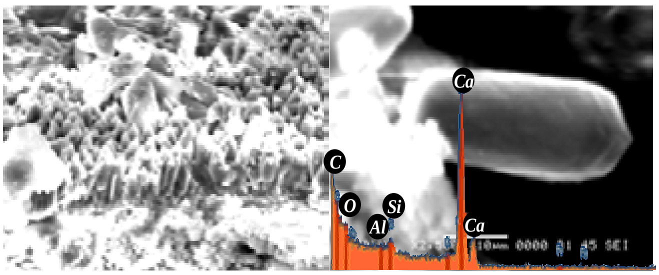


Photo 3:Specimen D bottom surface(φ100mm)

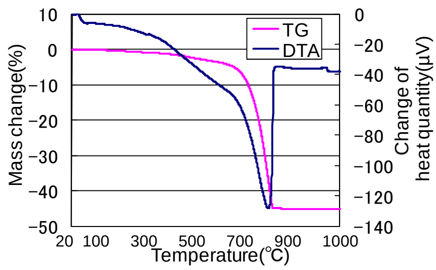


Figure 9: TG-DTA(φ100mm Specimen D bottom surface)

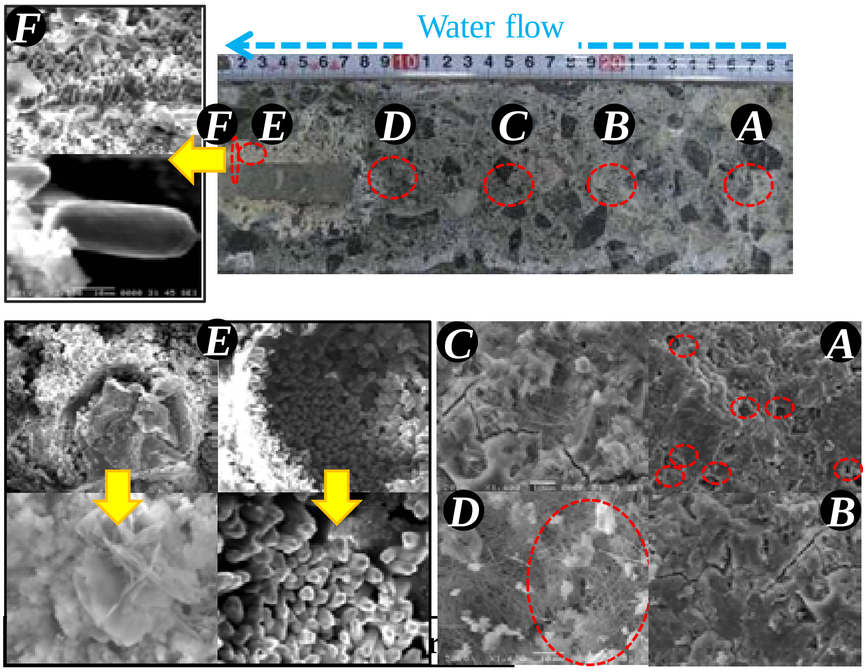


Figure 10: 100mm Cross-section of specimen

From these results it is supposed that there are various phenomena brought by repairing material including self-healing agents, such as the spreading of repairing materials, the formation of $CaCO_3$, the swelling effect by alumina-silicate hydrate, the expansive action by the formation of the ettringite, and the re-hydration by the formation of $Ca(OH)_2$ in the crack area.

4. CONCLUSTIONS

1. The addition of self-healing agents to the shotcrete seems to improve waterproof effects, which are attributed to the formation $CaCO_3$, $MgCO_3$, and magnesium silicate phases at crack surface under the water leakage condition.

2. It was supposed that repair material having self-healing capability and waterproof effect could be manufactured by using inorganic self-healing agents.

3. It is considered that the utilization of self-healing agents with appropriate dosage has a possibility as new repairing methods for cracked concrete under the water leaking situation, which is common among underground structures.

REFERENCES

T.H. Ahn "Development of self-healing concrete incorporating geo-materials, A study on its mechanism and behavior in cracked concrete" , Ph.D. dissertation, Dept. of Civil Engineering, The University of Tokyo, Japan ,2008.

T.H. Ahn, T. Kishi "New method as the self-healing design to repair cracks in cracked concrete", Proc. of 4th International Conference on Construction Materials : Performance, Innovations and Structural Implications, pp. 1339- 1346, Nagoya, Japan, Aug. 24-26 (2009)

The Driving force of Private Sectors Emerged in 1999 Taiwan Earthquake Condominium Reconstruction

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ABSTRACT

Condominium is the major housing form in the city, but also a latent problem when it comes to post-disaster reconstruction. The private sector emerged as a driving force in the condominium reconstruction process while the government with limited power to intervene in private properties, and little market profit making housing developers retreat from investing. This study discusses following issues by the experiences of "921 Earthquake Relief Foundation", a key NGO assisting in condominium reconstruction, and the interviews of 11 condominium communities in Taichung City and Taichung County in Taiwan.

The fist issue is the formation of cooperation partnership for reconstruction. It discusses the allocation of responsibilities and establishment of cooperation relations among the condominium communities, private foundations and government departments during the reconstruction process.

The second issue is the reconstruction mechanism based on the cooperation partnership. This issue analyzes the reconstruction results created by the interaction among developing community collective resources, removing obstacles, and accessing external assistances.

It is found that, at the community level, rather than economic resource, but community consensus and leadership were the two essential community collective resources for condominium reconstruction. Secondly, at state level, "921 Earthquake Relief Foundation" played a big role in substituting the government to concentrate and transmit society resources, and empowered the communities simultaneously. Thus, it is suggested that to foster the capacity of private sector to participate in public affairs is an important strategy for disaster mitigation and post-disaster recovery.

Keywords: *earthquake, reconstruction, condominium*

1. INTRODUCTION

1.1 Background & Objective

The Chi-Chi Earthquake, Magnitude7.3, hit central Taiwan in September 1999, which was believed to be the most severe disaster in the past 100 years in Taiwan. A total of 50,625 housing units were severely damaged, including 153 condominiums (10,974 households), accounting for over 1/5 of all collapsed housing. In 2006, after the reconstruction period, about 57.84% of the collapsed condominiums were successfully reconstructed (921EPRC, 2006).

Condominium reconstruction associated with complex problems of property adjustment and with little market profit, kept the government and housing developers from being involved, and posed the communities to conduct the reconstruction business by themselves. Unexpectedly, through the reconstruction process, a unique private force appeared in the private sector, the reconstruction communities and “921 Earthquake Relief Foundation, 921ERF”in particular.

Thus, this study aims to explore the key issues of self led reconstruction in the condominium community. More specifically, we are interested in the formation of cooperation partnership between the communities, NGO, and the government department, and the reconstruction mechanism by which the community developed their collective resources, removed obstacles, and accessed to external assistances.

1.2 Method & Data

In this study, Taichung City and Taichung County, as the biggest metropolis in central Taiwan and one of severe disaster-hit areas, were selected to be the study areas.

The research materials were mainly constituted by governmental archives and face-to-face interviews. Interviewees included superintendents related to reconstruction department in Taichung City and Taichung County government, the members of 921ERF in charge of guiding condominium reconstruction, and the leaders of community renewal committee. 11 intervened communities were selected according to the community size, and the interviews were held at September 2008, and February 2009 (Table 1).

This study was conducted in two phases. Firstly, it discussed the interaction performance between reconstruction resources, obstacles, and external assistances, according to the experiences of all the 25 failure cases in the study area. Secondly, it explored how the communities developed their collective resources, i.e. community consensus, public participation, organizational operation, and leadership, applying in reconstruction business, by the experiences of 11 successful condominium communities.

2. Characteristics, resources, and obstacles

As Komori (1997) suggested, compared to single building, the condominium with characteristics of both high-rise building type, and community living style, accordingly derives the unique collective resources and obstacles for reconstruction (Figure 1).

Summing up our investigation result, ownership, consensus, financing and coordination could be considered to be the top four main issues influencing reconstruction , which showed as follows：

(1) Interest conflict due to different positions
The confrontation positions coming from the variant land value in the mixed use community, or the opposite expectations for reconstruction between residential owners and developer owner always raised disputes or litigations and then delayed reconstruction progress.

(2) Joint ownership problem
It was hard to excess the threshold proportion of ownerships committed to rebuild, and the heavy burden of compensation to withdrawer went beyond those participants' affordability.

(3) Difficult to receive finance
Attributed to the high risk of financing to the community with households of variant financial capacity and economy credit, it was not easy for the communities to receive the funding for rebuilding projects.

(4) Co-structure problem
In Taiwan, the building structure of condominiums usually jointed in the same basement, it caused technical difficulties and safety concerns when the collapsed buildings rebuilt.

(5)Lack of operational ability
Sudden change in the role of developer, communities were lack of operational ability when they took up the responsibility of self led reconstruction in the after math of earthquake.

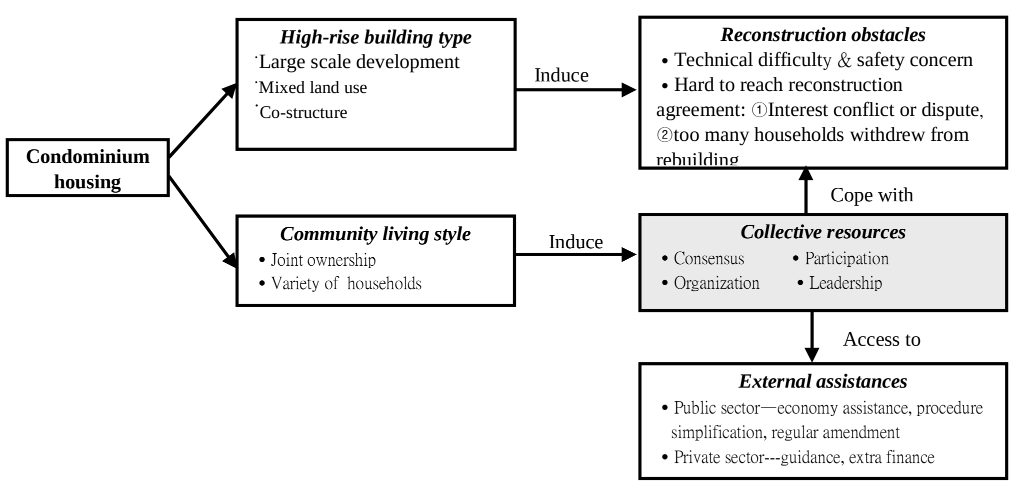


Figure1 Relationship between condominiumy characteristics , and reconstruction resources and obstacles

3. External Assistance

3.1 Public sector

In terms of public assistance, according to "Provisional Statute For September 21 Earthquakes Disasters Reconstruction 九二一震災重建暫行條例 ", the authority lowered the threshold proportion of the ownerships committed to rebuild, and increased the floor area ratio to subsidy reconstruction costs. However, the countermeasures did not work, while there were too many empty houses in Taichung area, most of the collapsed condominiums were located on non-profit locations, and meet housing market downturn during the rebuilding duration simultaneously. In economy assistance, the central government provided free / low-interest loans to support rebuilding funding; moreover, it innovated the" Negotiation loan assumption " scheme allowing affected households offset their previous home loans obligations with collapsed house and land property, which effectively lift the burden of double loans on affected households.

3.2 Private sector

"921 Earthquake Relief Foundation, 921ERF" , a NGO established by 921 Earthquake donations, supervised by social leaders, and directed by Professor Xie, a professor of Taiwan University, play a significant role in guiding and financing community reconstruction. For ownership's problem solving, 921ERF made up for the restraint that the government can not intervene or aid private property, implementing the " Blessing Program 臨門方案", by which it bought out the ownerships which were unwilling or unable to participate reconstruction, and proved interest-free loan to finance communities during the rebuilding period. To ensure the reconstruction quality, professional consultancies were introduced to supervise rebuilding process. it also set up a "Family of Blessing Program ", via symposiums, learning courses, site visit, to improve their operating capacity and encourage their confidence. " Blessing Program " not only provided practical assistances, but also accompanied the communities to go through the rebuilding process. Consequently, it helped 5,410households (70 plots) to rebuild, and got back 228 housing unites, with total spending eight billion NTD, and earned great praise.

4. Stakeholders, organization, and role allotment

As the reconstruction process is a collaborative process, it needs communities, NGO, professional bodies, and the government work together to successfully accomplish reconstruction task. To overcome the problems of information transmission, department coordination, and barriers identification and elimination, a three-level interaction network, in which community acted as a center linking local society, and central government, was developed. Characterized in that each level had a host subject associated with an intermediate unit playing contact, coordination and guidance functions, and then The 921 Earthquake Post-disaster Recovery Commission,921EPRC, responsible for leading the reconstruction affairs in central government, along with 921ERF ran through each level to integrate all the members. The illustration of stakeholders, contact relations and division of

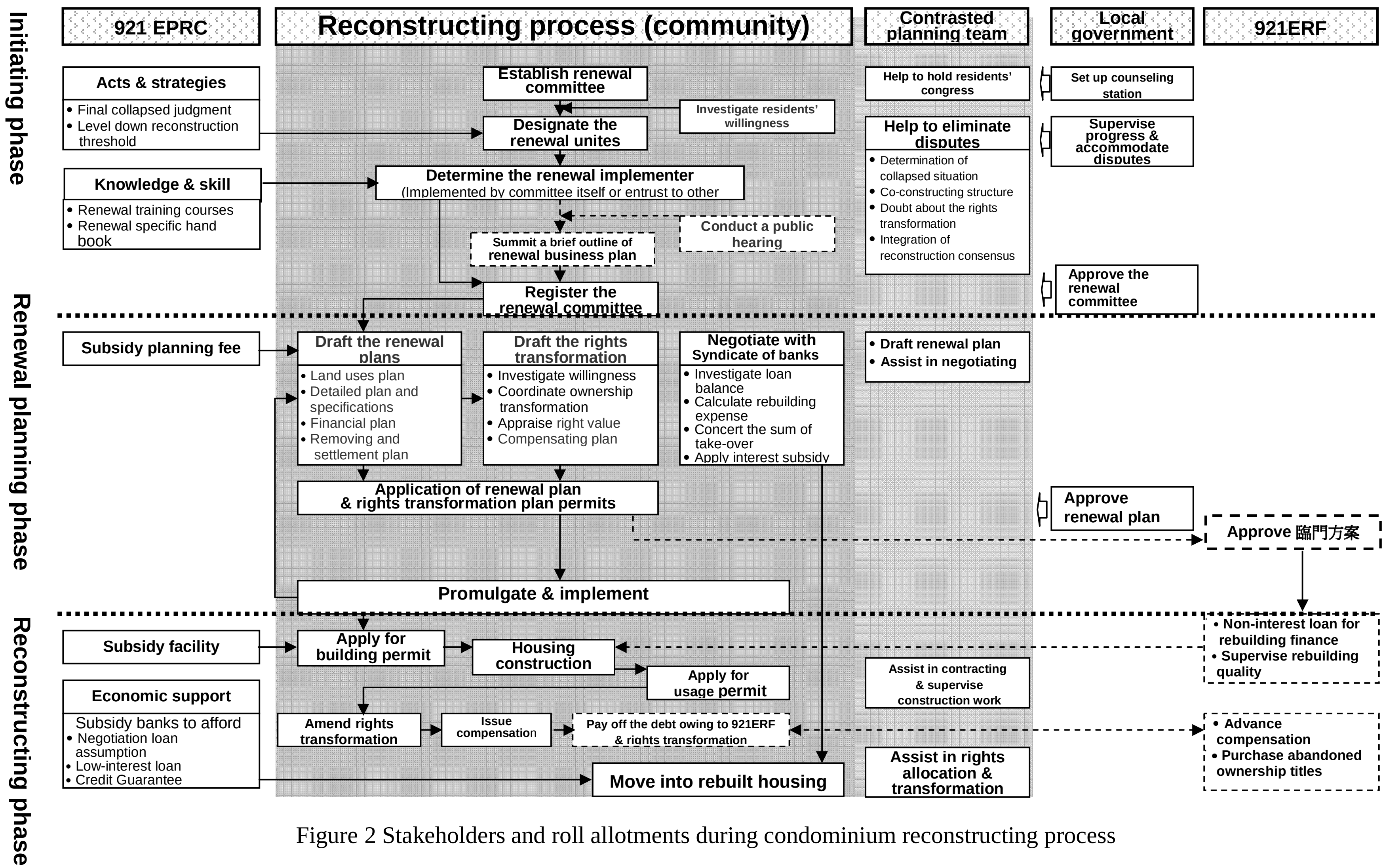


Figure 2 Stakeholders and roll allotments during condominium reconstructing process

tasks please refer to Figure 2, and Figure 3.

Subjects & intermediary

(1) Community level---community & commissioned Planning and design team (link：community, local government, and 921 ERF)

(2) Local level --- local government & commissioned consultant group (link：local government, and community)

(3) Central level---Executive Yuan &921EPRC(link：Central government, local government, and 921EF)

(4) 921ERF(Link：921EPRC, communities, professional groups, and banks)

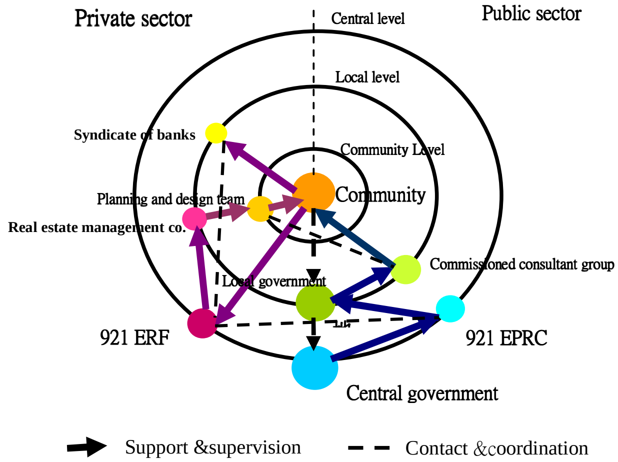


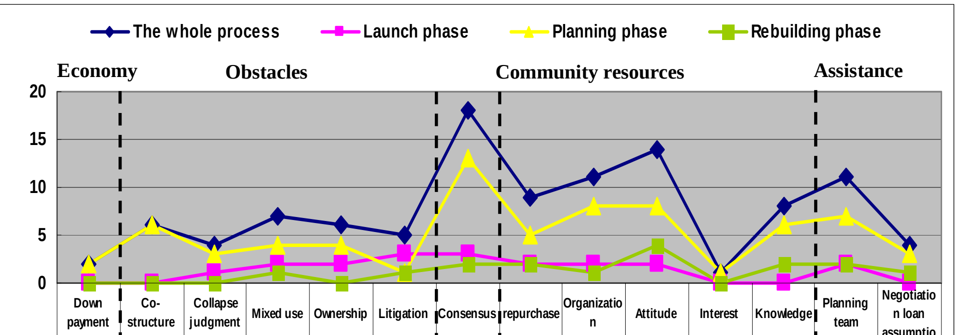
Figure 3 Stakeholders and interaction network

5. Reconstruction result & case study

In Taichung County and Taichung City, there were 72 (size range between 10 to 801housing unites) condominium buildings collapsed, of which 47 buildings were rebuilt, spending 4~7 years after 921 Earthquake. 43 rebuilding condominiums were supported by “Blessing Program”. The remaining 25 condominiums, because of disputes on collapsed judgment or interest conflict over ownership adjustment, had not yet begun to rebuild at the end of reconstruction period.

5.1 Resources, obstacles, and external assistances

Though the experiences of 25 abandoned communities, it was found that in addition to the reasons of community size and missing the timing of launching the reconstruction business, the failure causes mainly focus on insufficient collective resources：Weak consensus (rank=1, N=18), loose community organizations and residents with low willingness to participate (rank 3, N = 11), and the leader not interested in the reconstruction work (rank 2, N = 14) or lack of implementation



	Down payment	Co-structure	Collapse judgment	Mixed use	Ownership	Litigation	Consensus	repurchase	Organization	Attitude	Interest	Knowledge	Planning team	Negotiation loan assumptio
The whole process	2	6	4	7	6	5	18	9	11	14	1	8	11	4
Launch phase	0	0	1	2	2	3	3	2	2	2	0	0	2	0
Planning phase	2	6	3	4	4	1	13	5	8	8	1	6	7	3
Rebuilding phase	0	0	0	1	0	1	2	2	1	4	0	2	2	1

Figure 4 Analysis of failure causes of condominium reconstruction
---community resources, obstacles, and external assistances

Source: Taichung City government, and Taichung County government; adapted by author capacity (Rank 6, N = 8). Second is the issue of external assistances：The contracted consultant lacking of professional competence, or dropping out of the project (rank 3, N = 11). Unexpectedly, individual household's economic problems, i.e. insufficient down payment, were not serious (N = 2). It confirms the opinion of this study that the collective resources are more important than individual economic resources, and a lack of the capacity to access to external resources will more likely result in vulnerable reconstruction result (Figure 4).

5.2 Successful experiences of self led reconstruction

In this study, 11 communities were interviewed and their basic information was illustrated as table 1. According to their experiences, we explore their formation of collective resources, leadership performance, and organization operation, to identify the relationship between the collective resources and successful reconstruction. Through interviews, we found that the meaning of successful reconstruction is not only for the community to overcome extreme difficulty to regain their homes, but also to develop their own potential. More importantly, they created a new community empowerment experience in Taiwan.

(1) Building reconstruction consensus

Strong community sense and clear analysis of the advantages and disadvantages of reconstruction immediately after disaster is the key point of building reconstruction consensus. Yi Shu 藝術 Community, the first rebuilt community by way of renewal, is a community full of strong community sense; Pre-disaster, they had held regular monthly party and clean-up activities, and initiated the slogan "creating a safety, peace, and harmony community" to encouraged themselves. On the third day after the disaster, they gathered in the neighborhood center and reach initial consensus of rebuilding under candlelight. (Leader Liu) Simple and clear explanation of the pros and cons is the basis of reconstruction

Table 1 Basic information of interviewed communities

Community	Scale hh		Duration	Community composition	Socio-economic conditions of the leader
	Pre-	Post-			
A-1 Wen Xin 文心 community	445	270	6Yrs,8Mos	employee, labor, landlord, shop owner	Female, 40s, high school, employee
A-2 Tai Zi 太子 Community	198	197	4Yrs,5Mos	civil servant, labor, landlord, shop owner	Female, 30s, high school, shop owner
A-3 Long Ge 龍閣 Community	167	40	5Yrs,2Mos	landlord, employee, trader	Male, 40s, collage, trader
A-4 Yuan Jian 遠見 Community	106	106	5Yrs,4Mos	civil servant, service trade	Male, 50s, collage , retired civil servant
A-5 Tian Xia 天下 Community	132	105	7Yrs,3Mos	employee, labor, shop owner	Male, ,50s, collage, owner of land administration office
B-1 Xiang Yang 向陽 Community	78	75	4Yrs,11Mos	employee, service trade, civil servant, shop owner	Male, 60s, high school, designer
B-2 Feng Tian 豐田 Community	78	73	---	employee, labor, shop owner	Female, 60s, Primary school, employee
B-3 Yi Shu 藝術 Community	56	56	3Yrs,1Mos	civil servant, employee	Male, 60s, collage, retired civil servant
C-1 Zhang Xing 中興 Community	38	38	---	professor, employee, vendor, shop owner	Female, 60s, doctor, professor
C-2 Jin Xiang 錦祥 Community	20	20	7Yrs,6Mos	landlord, employee, labor,	Female,40s, high school, owner of housing agency
C-3 Wei Dau 衛道 Community	18	18	5Yrs,3Mos	employee, labor, landlord	Female, 40s, high school, accountant

Note: A >100、B 41~100、C <40 households, divided according to the standard of renewal subsidy
Source:921ERF, and interviewed communities; adopted by author.

consensus building, by which residents can judge whether reconstruction is worthy and reduce the delay time for hesitation(A-1WenWin 文心 Community director-general Lin).

(2) Reconstruction leaders emerging from grass roots

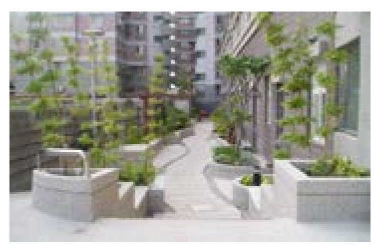
This time, most of the chairman and the director-general of the community renewal committee were served by housewives, blue collar workers and farmers. Not willing to let their home became wasteland they resolutely took up the task of the rebuilding leaders. With the unswerving determination and enthusiasm, they visited previous neighbors one by one across all the Taiwan persuading them to come back to participate reconstruction. In the beginning, they even not knowing about rebuilding works, nor how to conduct a meeting, by way of trial and error and the guidance from 921ERF, eventually they overcame all the difficulties and accomplished reconstruction mission. It really the magic power of grass-roots society revealed in the recovery process. They unanimously believed that after reconstruction they not only regain their home, but also deepen their community consensus. (Mrs. Peng, leader of B-2 FenTian 豐田 Community; Mrs. Zhang, leader of C-2 Jin Xiang 錦祥 Community; Mrs. Wu, leader of C-3Wei Dau 衛道 Community)

(3)Reconstruction community operation

As a variety of residents living in the community, if we can explore their expertise to serve community works, on the one hand it can heighten residents' self-awareness and enhance their interest on the reconstruction, and can promote neighbor relationships via mutual inspiration to maintain reconstruction confidence on the other, Mr. You , director-general of Tai Zi 太子 Community, said. The followings were their experiences：

Collapsed condition of XingYiang 向陽 Community

Reconstructed condition of XingYiang 向陽 Community



Reconstructed condition of Long Ge 龍閣 Community

Children panting class

Site visit

Blessing Program Congress

Source：XingYiang 向陽 Community, Tai Zi 太子 Community's website, and author

A. Construct the website & issue periodical

In order to share community information to boost mutual trust and enhance residents' concern about reconstruction affairs, they set up the website and issued periodical to post community events, administrative information of the community renewal committee, reconstruction progress, financial reports, and seismic test results, etc.; also set the column for opinion exchanges to eliminate misgivings.

B. Calling residents with specialty together to join in volunteer team

To promote reconstruction works, Tai Zi 太子 Community called the residents together to form community volunteer teams to serve as administrative staffs or the teacher for various learning courses.

C. Giving training courses and learning classes

There is also training courses, led by the residents with professional expertise of enterprise, legal, or public affairs, via education and training activities to enhance volunteers' capability applied in community administration tasks. They held learning activities such as painting, writing classes for children and computer class for residents as well. Learning along with the progress of reconstruction made residents feel full of energy**.**

E. Experiences exchange

Sometimes Tai Zi 太子 Community also associated with 921ERF to hold site visiting or workshop to pass on their reconstruction experiences to the other communities.

6. CONCLUSIONS

(1) Collective resources and reconstruction opportunities

Compared to individual reconstruction, collective reconstruction heavily rely on community resources, that reveals a opportunity to get rid of the retrain of individual households' social-economic situation, and to enhance reconstruction capacities by way of community empowerment in the aftermath of severe disaster.

(2) Networks and intermediaries are essential for community empowerment

Condominium reconstruction is not only community's own affairs, but also the cooperation result of community, government, and intermediary. The experience of 921ERF enlightened us that the intermediary is essential in assistance in the affairs of information transmission, guidance, and coordination, when the authority implementing reconstruction supporting policies. With their assistances, communities can enhance their ability for self led construction immediately after disaster.

(3) Private force is an indispensable prop for disaster mitigation and post-disaster recovery

The principle of Taiwan government's reconstruction policy, not directly intervening in the reconstruction affairs as much as possible, unexpectedly boosted the vigorous private force and got a great achievement. The wave of self development in civil society, not only occurred in the upper classes of society

(921ERF), more generally occurred at the grassroots level (renewal communities). Therefore, how to develop a social environment which can stimulate the potentials of private forces, and effectively induce them involved in the disaster mitigation and post-disaster recovery affairs, is a critical issue for us to consider.

REFERENCES

921 Earthquake Relief Foundation, 2006. Report on "Blessing Program 臨門方案", Website:http://www.taiwan921.lib.ntu.edu.tw/

Chang Fang Engineering Consultants, Ltd., 2005. ***Report on the Advisory Service for Housing and Community Renewal in Taichung County***, Taichung Taiwan.

David W. McMillan, Nashville, and Tennessee, 1996. Sense of community: A definition and theory. ***Journal of Community Psychology***, 24(4), 315-325.

Honda Assets Valuation Co. Ltd., 2004. ***Final Report on Follow-up Consultant service for 921 Earthquake Reconstruction in Taichung City***, Taichung Taiwan.

Hobfoll, S. E. (1998). ***Stress-, Culture, and Community：The Psychology and Philosophy of Stress***. New York：Plenum.

Lyouzi, M.T., 1999. ***Condominium Reconstruction--- Struggle against Hannsinn Earthquake***, Tokyo：NIKEI Architure.

Talen, E. (1999). Sense of Community and Neighborhood Form**:** An Assessment of the Social Doctrine of New Urbanism Emily. ***Urban Studies***, 36(8), 1361-1379.

The 921 Earthquake Post-disaster Recovery Commission, EY, 2006. ***Review of Housing reconstruction after 921 Earthquake***, Taichung Taiwan.

Yap, K.S. (1999). Community Participation in Low-income Housing Projects: problems and prospects. ***Community Development Journal***, 25(1), 56-65.

Influence of resin properties on the shear capacity of RC beams repaired by TST-FiSH

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ABSTRACT

After disasters such as earthquakes it is necessary to quickly repair damage in order to ensure safety and speed recovery efforts. However, conventional methods require large-scale operations and the repair effect may be delayed. Therefore, the authors proposed an emergency rapid retrofitting method utilizing fiber sheets containing hydraulic resin (TST-FiSH) for the repair of reinforced concrete structures. The goals of this new method are to provide higher safety, speed, and ease of application compared to conventional methods. The basic properties of TST-FiSH and the repair effect have been investigated, and in this paper the influence of resin material properties on the shear capacity of RC beams repaired by fiber sheet is reported. It was experimentally understood that the joint strength between fiber sheets is an important factor for improving the shear capacity of RC beams even if the bond and adhesion strengths between fiber sheet and concrete surface are not so strong.

Keywords: hydraulic resin, continuous fiber sheet, shear capacity, joint strength

1. INTRODUCTION

In Japan, the importance of a seismic reinforcement in concrete structures was realized after the Hanshin/Awaji great earthquake disaster of 1995. Seismic reinforcement improves ductility primarily by avoiding the brittle “shear fracture” which occurs in column members. Main transportation and emergency transportation roads in the Tokyo metropolitan area are mostly reinforced by this method; however, there are still many structures which may suffer damage due to the magnitude of the earthquake. In addition, new structures cannot avoid damage, as they are designed to permit some damage during a large-scale earthquake. When structures are damaged by natural disasters, they require emergency retrofitting to ensure safety and functionality. Conventional methods, however, cannot adequately cope with subsequent aftershocks, and large-scale repair works are time consuming. From a concept inspired by medical plaster casts, a new repair method utilizing fiber sheets containing hydraulic resin (TST-FiSH) was developed to address this problem. This method can repair reinforced-concrete structures through the hardening effect of hydraulic resin when sprayed with water, and can provide higher safety, speed, and ease of application compared to conventional methods (Figure 1).

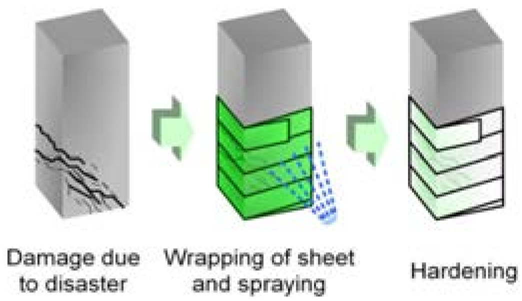

Figure 1: Conceptual figure of proposed method

The fiber sheet is lightweight and can be wrapped around structures of various forms and this method utilizes the fiber sheet containing hydraulic resin as a finished product. By utilizing a manufactured product, construction time is reduced compared to conventional methods since it is not necessary to apply an adhesive to the structure or to perform extensive preparations. The repair effect of TST-FiSH using different types of fiber sheets such as carbon, aramid or vinylon was examined experimentally in a previous investigation, and it was confirmed that the shear capacity could recover to the same level or higher than before damage occurred (Suzuki et al., 2009). The handling of the aramid fiber sheet was easiest from the construction performance viewpoint, and its construction time was less than 1/3 that of a conventional method. This is the most significant advantage of this method because we can reduce the repair cost. However, the reliability of the hydraulic resin is less than that of the epoxy resin in construction field repair works. In order to improve the reliability for practical use, the detailed mechanism, especially the influence of hydraulic resin properties on the shear capacity of RC beams, should be examined. In this study, two types of hydraulic resin and an epoxy resin were prepared to understand this influence.

2. EXPERIMENTAL PROCEDURE

2.1 Material properties

The hydraulic polyurethane resin (viscosity : 35,000～45,000 mPa･s at 25℃) used in this study is a single liquid-hardening resin which reacts and begins hardening after contact with water and in the presence of carbon dioxide. The hydraulic polyurethane resin was diluted with glycol ether solvent (HPR-A) or reactiveness monomer (HPR-B) because the pure resin was difficult to handle due to high viscosity. The amount of resin spreading on an aramid fiber sheet is 0.45 kg/m^2 and 0.85 kg/m^2, respectively. For the repair procedure, the fiber sheet impregnated with the resin is applied on the test specimen.

The epoxy resin (viscosity : 20,000 mPa･s at 20℃) used in this study, which is widely used as a resin for continuous fiber sheets in the construction field, is a double liquid-hardening resin. The amount of resin spread on an aramid fiber sheet is 0.8 kg/m^2, and the repair procedure is as follows. The primer is spread on the test specimen and the undercoat resin is spread, then the fiber sheet is applied to the specimen, followed by the topcoat.

The physical properties of the aramid fiber sheet used in the experiments are shown in Table 1.

Table 1: Physical properties of aramid fiber sheet

Sheet type	Weight (g/m^2)	Tensile strength (N/mm^2)	Young's modulus (N/mm^2)	Fracture strain (%)
Aramid	280	2,060	1.18×10^5	1.8

2.2 Mechanical tests of fiber sheet impregnated with resin

2.2.1 Tensile test

Tensile test of the fiber sheet and the fiber sheet impregnated with the resins was conducted following JSCE-E 541-2007 (Japan Society of Civil Engineers). The fiber sheet impregnated with the resins was cured in the air (20℃, RH60%) for 7 days. Tensile strength (f_{fu}) and Young's modulus (E_f) were calculated by Equations (1) and (2), respectively.

$$f_{fu} = \frac{F_u}{A} \tag{1}$$

$$E_f = \frac{F_{60} - F_{20}}{(\varepsilon_{60} - \varepsilon_{20}) \cdot A} \tag{2}$$

where, F_u: maximum load (N), A: cross sectional area (mm^2), F_{20}, F_{60}: load at 20% or 60% of maximum load (N), ε_{20}, ε_{60}: strain at F_{20} or F_{60}

2.2.2 Joint test

Joint test was conducted following JSCE-E 542-2007. The curing condition was the same as the tensile test. The joint length was changed (150mm, 200mm, and 250mm), and joint strength (f_{fus}) was calculated by Equation (3).

$$f_{fus} = \frac{F_u}{A} \tag{3}$$

2.2.3 Bond test

Bond test was conducted following JSCE-E 543-2007. The curing condition was the same as the tensile test. Bond strength (τ_u) and de-bonding energy between fiber sheet and concrete interface (G_f) were calculated by Equations (4) and (5), respectively.

$$\tau_u = \frac{P_{max}}{2b \cdot l} \tag{4}$$

$$G_f = \frac{P_{max}^2}{8b^2 \cdot E_f \cdot t} \tag{5}$$

where, P_{max}: maximum load (N), b: width of fiber sheet (mm), l: effective length of fiber sheet, t: thickness of fiber sheet (mm)

2.2.4 Adhesion test

Adhesion test was conducted following JSCE-E 545-2007. The curing condition was the same as the tensile test. Adhesion strength (f_{au}) was calculated by Equation (6).

$$f_{au} = \frac{F_{au}}{A_s} \tag{6}$$

where, F_{au}: maximum load (N), A_s: area of steel jig (40mm× 40mm: mm^2)

2.3 Loading test of RC beam repaired by fiber sheet

The repair effect of TST-FiSH was evaluated using beam specimens under two-point loading. Specimen dimensions are shown in Figure 1 and specimen specifications and material properties are given in Table 2. The beam was repaired by wrapping TST-FiSH in a single-layer in the shear span (Figure 2) with a 200mm overlap on top of the beam. Loading test was conducted after 7 days curing. Loading was applied one-directionally with gradual but steady increase. Cracks were observed visually and load, vertical displacement, axial reinforcement strain and shear reinforcement strain were measured.

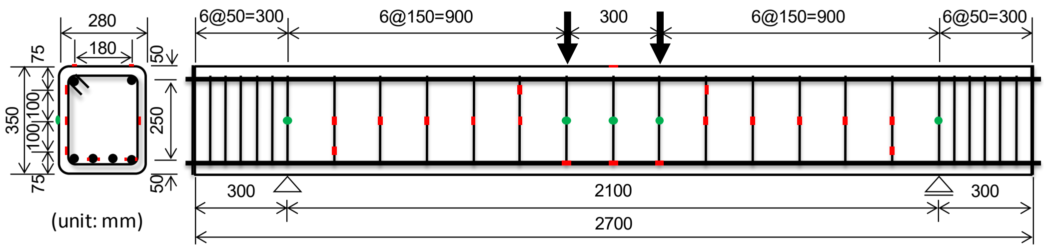

Figure 1: Beam specimen dimension

Table 2: Specimen specifications and material properties

No.	d (mm)	a (mm)	a/d	Main rebar		Shear reinforcement		Fiber sheet	Resin
				Material	Steel ratio (%)	Material	Steel ratio (%)		
1	300	900	3	SD490 D29	3.06	SD295A D6	0.15	-	-
2								Aramid	Epoxy
3									HPR-A
4									HPR-B

Concrete	Compressive (N/mm^2)	Young's modulus (N/mm^2)	Reinforcement	Yield (N/mm^2)	Tensile (N/mm^2)	Young's modulus (N/mm^2)
No.1	32.5	2.43×10^4	SD490 D29	523	677	1.87×10^5
No.2	30.6	2.35×10^4				
No.3	33.5	2.45×10^4	SD295A D6	349	506	1.82×10^5
No.4	32.5	2.43×10^4				

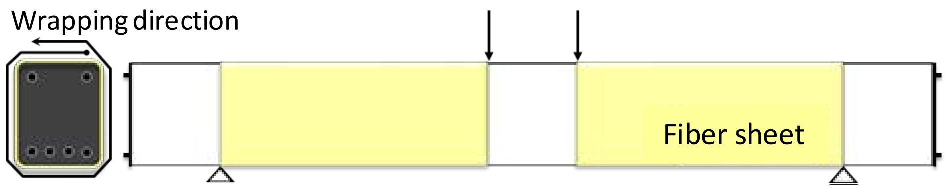

Figure 2: Repaired specimen

3. EXPERIMENTAL RESULT AND DISCUSSION

3.1 Physical properties of resins

3.1.1 Tensile test result

Tensile test results are shown in Figure 3. The tensile strength of the fiber sheet with resin was mostly same although the young's modulus of epoxy type was smaller than that of HPR series.

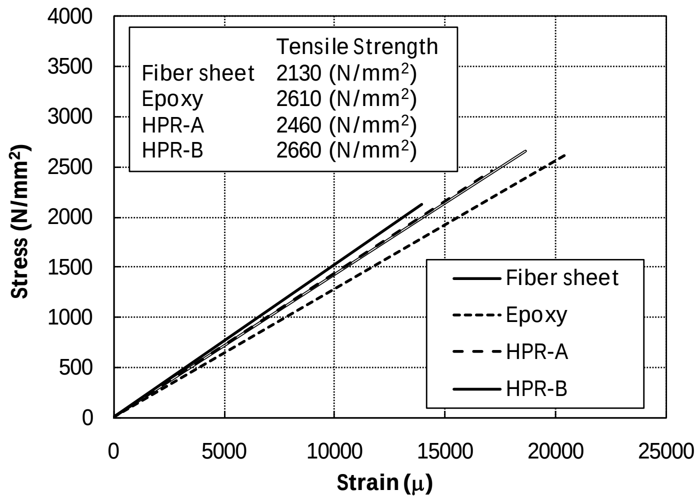

Figure 3: Tensile test result

3.1.2 Joint test result

Joint test results are shown in Figure 4. In the case of epoxy, fracture within the joint part was not observed so that the joint strength was same as the tensile strength of the fiber sheet with epoxy resin. In the case of HPR-A, the joint strength was smaller than the tensile strength of the fiber sheet with HPR-A, although fracture mostly happened in the non-joint area. In the case of HPR-B, the joint strength was very weak compared with other cases and fracture happened in the joint area. The joint strength was mostly the same although the joint length changed depending on the case.

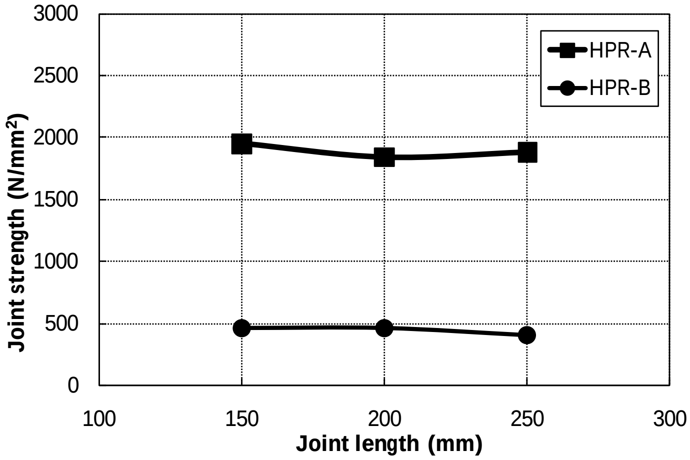

Figure 4: Joint test result

3.1.3 Bond test result

The de-bonding energy between fiber sheet and concrete interface (G_f) and the bond strength are shown in Figure 5. The de-bonding energy and the bond strength of epoxy were higher than those of other resins. In the case of HPR-B, the de-bonding energy was quite low though the bond strength was almost the same as the epoxy. In the case of HPR-A, the de-bonding energy was not so low though the bond strength was not so high.

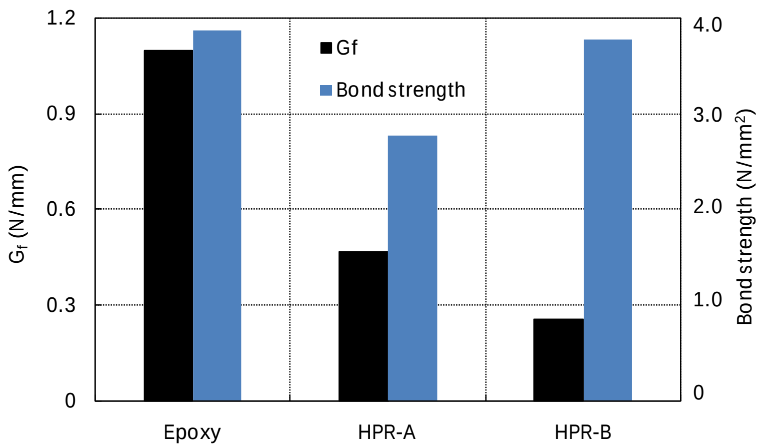

Figure 5: G_f and bond strength

3.1.4 Adhesion test result

The adhesion strength of epoxy, HPR-A and HPR-B was 5.1 N/mm^2, 2.1 N/mm^2 and 3.2 N/mm^2, respectively.

3.1.5 Summary of material test results

A summary of the above material test results is shown in Figure 6 using a radar chart and normalizing by the test results of epoxy (100%). It could be understood that the epoxy resin showed higher performance and the material properties of HPR series showed different properties. Therefore, the influence of resin properties on the shear capacity of RC beam repaired by fiber sheet may be clarified by using these different types of material.

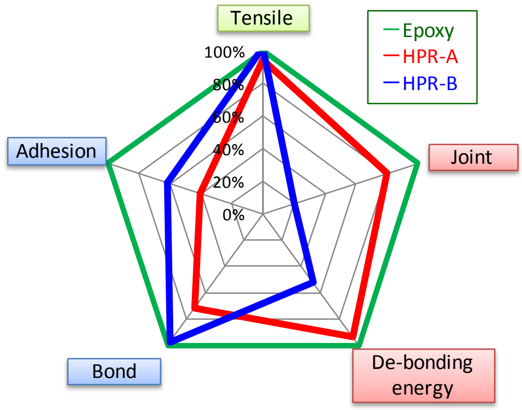

Figure 6: Summary of material test

3.2 Loading test result

The load displacement curve is shown in Figure 7. The fracture mode was shear fracture after yielding of the shear reinforcement in all cases. It could be clearly understood that the HPR-A (No.3) showed mostly same repair effect as the epoxy one (No.2) though the adhesion strength and the bond strength were very small. In the case of HPR-B (No.4), the repair effect was smaller than epoxy and HPR-A; however, the maximum load was almost twice that of the non-repaired RC beam (No.1). When comparing with the material test results (Figure 6), it was considered that the joint strength and the de-bonding energy were important factors to increase the shear capacity of RC beam. On the other hand, the bond strength between the fiber sheet with resin and the concrete was not important. In order to verify this consideration, two additional test cases were conducted.

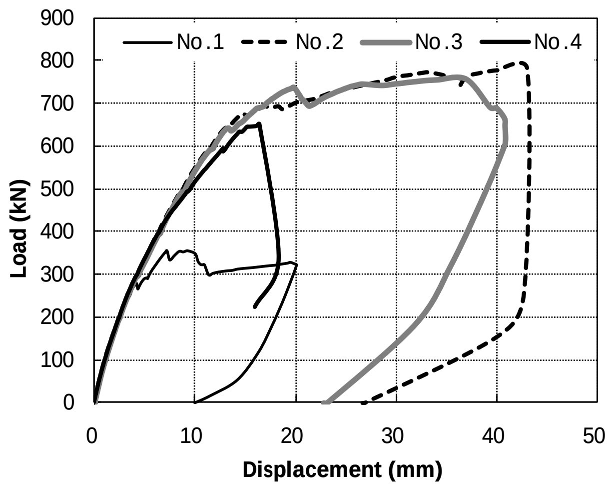

Figure 7: Load displacement curve (No.1 – No.4)

3.3 Additional loading test and result

In order to clarify the influence of the bond strength on the shear capacity of RC beam, an RC beam without bonding between the fiber sheet using HPR-A and the concrete surface was made. In this specimen, only the joint strength between fiber sheets is effective to improve the shear capacity of RC beam.

Figure 8 shows the test result of the non-bonded case with the bonded case (HPR-A (No.3)). In the non-bonded case, the displacement was larger than that of bonded case because the bonding effect of fiber sheet contributed to reduce the total displacement of RC beam. However, the maximum load and displacement were almost same as the bonded case. From this experimental result, it was verified that the bond strength between the fiber sheet with resin and the concrete was not important. Furthermore, the shear capacity of HPR-B (No.4) might be improved if the joint strength would be improved by reinforcing.

The joint of HPR-B was only reinforced by epoxy resin and the joint strength of was around 730 N/mm^2, which is roughly 1.6 times the original HPR-B but only around 0.4 times HPR-A. Figure 9 shows the loading test result. The maximum load and displacement were improved and the maximum load was similar to that of HPR-A (No.3) although the maximum displacement was smaller than that of HPR-A (No.3). This was due to the weaker joint strength of the reinforced HPR-B. Through these additional loading tests, it could be concluded that joint strength is an important factor for improving the shear capacity of RC beam.

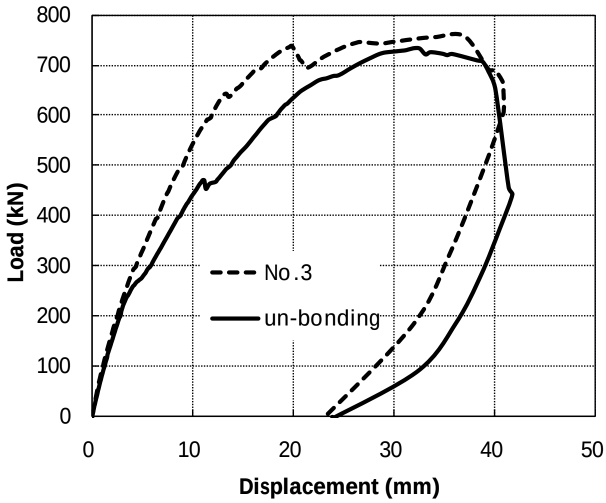

Figure 8: Load displacement curve (un-bonding case)

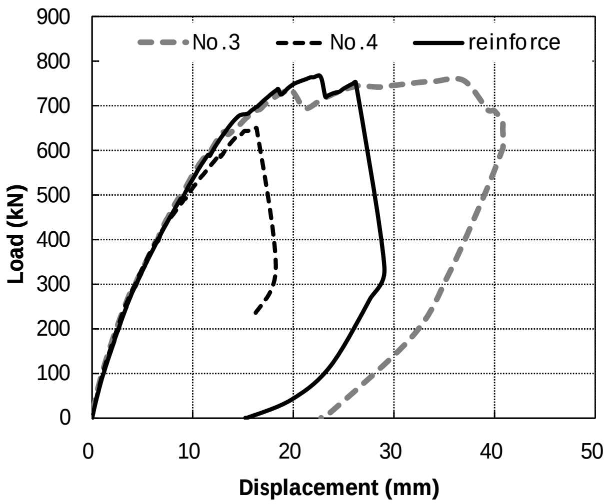

Figure 9: Load displacement curve (reinforced HPR-B)

4. CONCLUSION

In this paper, the influence of resin material properties on the shear capacity of RC beams repaired by fiber sheet was experimentally investigated. It was concluded that the joint strength between fiber sheets is the most important factor for improving the shear capacity of RC beams even if the bond and adhesion strengths between the fiber sheet and the concrete surface are not so strong.

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REFERENCES

Suzuki, M., Kasakura, R., Ito, M., and Kato, Y., 2009. Experimental Examination on the Repair Effect of Emergency Rapid Retrofitting Method TST-FiSH, *Proceeding of 8th international symposium on New Technologies for Urban Safety of Mega Cities in Asia*,